View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NORA - Norwegian Open Research Archives

Norges Handelshøyskole

Bergen, 2011 Spring

Master Thesis within Master of Science in Economics and Business Administration

Master in Energy, Natural Resources and the Environment

**Advisors**

**Prof. Dr. Mette Bjørndal and Associate Prof. Dr. Endre Bjørndal**

# Fixed Prices and Quotas for Renewable Electricity

**Case Studies and Implications for Norway**

Han Wu

This thesis was written as a part of the master program at NHH. Neither the institution, the supervisor, nor the censors are - through the approval of this thesis - responsible for neither the theories and methods used, nor results and conclusions drawn in this work.

# Abstract

This thesis provides a study on the support schemes for renewable electricity generation. In particular two schemes, namely Feed-in Tariff (FIT) and Tradable Green Certificate (TGC), are compared. The author analyzes the applications of the two schemes in the wind power markets of four different countries and takes a further look at the common certificate market that Norway and Sweden will enter in 2012. The country case studies reveal that the FIT system has advantages in stimulating new capacity, reducing risk and utilizing resources, while the TGC system ensures cost control and performs efficiently in meeting a policy goal within a limited time frame. The future Norwegian-Swedish common TGC market can help Norway to further utilize its hydropower resources and fulfill the international obligations. However, it should be aware that the technology-neutral design of the system may create windfall profit for lower-cost generators and thus lead to an allocation problem.

# Acknowledgement

I would like to express my deepest thanks to my supervisors, Vice Rector and Professor Dr. Mette Bjørndal and Associate Professor Dr. Endre Bjørndal. They provided me with very valuable help during the whole thesis writing process. I really appreciate their attitudes of being extremely detail-oriented and responsible. Writing the thesis with them is a great learning experience for me and I regard them as my role models in my future research life. In addition, they acted as my reference in my PhD application and I really appreciate their kind help.

I also want to thank Professor Dr. Gunnar Eskeland for giving me valuable suggestions through emails when I asked for help.

I would like to give this thesis to my mother, Bihua Yu, who gives me invaluable supports in all my life. My mother suffered from a cancer last year. I try to perform my best and show her the best of me. Moreover, the work would not have been completed without the support from my wife and I feel very grateful for that.

# Table of Content

# 1. Introduction

The development of renewable energy can enhance fuel security and provide environmental benefits. It is also regarded as the best solution to the challenge of climate change, an issue that has raised widespread public awareness at present. In the long term, renewable energy may become the dominant sources for world energy consumption, so many countries have long been putting strategic interests in fostering the early development of the markets.

Cost remains the core issue in the diffusion of renewables. As most of the renewable sources are not economically viable so far and their social benefits cannot be properly internalized financially, any further development requires supportive frameworks provided by the policymakers. The design of the policy incentives in many cases can determine the extent to which a market can grow. A well-designed support scheme can reduce the investment risk of the developers, and at the same time control the subsidy cost at a reasonable level and encourage future cost reduction. Conversely, the whole renewable industries can stop functioning due to a poorly set regulatory framework.

Support schemes to renewable industries can be generally divided as investment support and operating support (Cali et al, 2009). Investment support is defined as policies to facilitate the upfront investment of renewable projects. Examples of investment support includes capital grant, tax exemption, and so on. Operating support is more related to the operation of the projects and generation of electricity. It is often granted for every unit of renewable electricity generation. Compared to the investment support, operating support usually has more profound impact on the whole life of the project. This thesis aims at providing an international comparison of some existing operating support schemes.

There are two main types of operating support in the world's renewable industries today. The top 10 countries with highest wind capacity installed are all using either one of them to promote their domestic markets. The first method is the feed-in system, sometimes also referred to as a pricing approach, in which a fixed amount of compensation is given to renewable generators for every unit of electricity they generate to balance the extra cost from using unconventional sources. The payment can be either a feed-in tariff (FIT) that is above the market price, or a premium paid additionally on top of the wholesale market price. The countries using feed-in systems include for instance Germany, Denmark, China, France and Spain. The second method is the tradable green certificate scheme (TGC), which is often called a quota approach, boosting renewable development through setting renewable mandates for retailers and requiring them to buy green certificates in proportion with the total amount of electricity delivered. Green certificates are granted to renewable generators and can be sold or traded afterwards, serving as an extra income for the generators. Examples of countries adopting a TGC scheme are the UK, Sweden, Italy (combined with a FIT) and many states in the US.

There used to be other types of support mechanisms for renewable energy. For instance, the UK and China used to implement a tendering system. In such a system tenders are often invited to compete for a certain financial budget to construct a certain capacity of renewable generation. However, most of these systems are abandoned now and the pricing and quota approaches are the most common choices for regulators when considering new policies.

The objective of this paper is to provide an international comparison on the effectiveness of the two mechanisms in promoting renewable energy. Four country cases are evaluated: Germany and Denmark are used as representatives for the pricing approach, and the US (represented by Texas) and the UK are examples of the quota approach. In most part of the paper, the author focuses the analysis on the wind power industry. The analysis on other sources is provided separately in a renewable diversity discussion.

The reason for choosing wind as a main focus is its high maturity as an unconventional renewable source and some of its key characteristics that are shared among many renewable sources, such as high capital input, low variable cost and long investment cycle. These characteristics have a deep implication on the design of the support policy. In addition, most of the countries have policy frameworks specially designed to promote wind power, offering a high degree of comparability. Not all the countries have policy incentives designed for other sources.

Based on the international comparison this thesis summarizes the main characteristics of the FIT and TGC schemes. After that, an evaluation is made on the potential influence of a TGC scheme on the development of green electricity in Norway. In September 2009 Norway and Sweden announced an agreement to establish a common green certificate market from January 2012. The purpose of the agreement is to further promote green electricity generation, especially to exploit the wind resources in Norway. The implementation of the policy is expected to have a profound influence on the renewable industry. This thesis discusses this issue based on the characteristics and practical experiences of the support schemes.

The structure of the thesis is as follows: Chapter 2 has a brief introduction of the economic mechanisms of the FIT and TGC；Chapter 3 elaborates on the economics of the wind power industry with a focus on the cost composition of the industry; Chapter 4 is an international comparison of the utilization of operating support schemes in four markets: Germany, UK, Texas and Denmark; Chapter 5 builds upon the country cases in Chapter 4 and provides a discussion on the main characteristics of the FIT and TGC; Chapter 6 looks at the future joint green certificate market in Norway and Sweden and evaluates the suitability for Norway to enter such a system. Policy suggestions are raised for a better design of the green certificate market. A conclusion of the thesis is given in Chapter 7.

# 2. Introduction of the Mechanism of FIT and TGC

This chapter gives a brief review on the theoretical background of the two support schemes, FIT and TGC. The discussion focuses on the mechanism of the two policies and how they can achieve the purpose of promoting renewable energy, as well as how they are affected by technological changes.

## 2.1 Feed-in Tariff

The feed-in tariff system is the traditional and most widely used mechanism to support green electricity. It requires the utility or the retailers to purchase the electricity produced by renewable generators at a tariff determined by the regulators. Renewable generation projects receive such a tariff for a long period, usually as long as 15 – 20 years. The tariff is set considerably higher than the price of wholesale electricity in order to compensate for the high cost of green electricity generation. In most systems the cost of paying the tariff will be socialized equally among the end-consumers of the country.

Suppose the wholesale electricity price is $P_0$ and at this price the quantity of green electricity developed is $Q_0$. The feed-in tariff should be set at a level higher than the wholesale price, for instance $P_a$. In the long term investors are encouraged to develop new sites until the marginal cost of producing renewable electricity (including capital cost) reaches the tariff level $P_a$. The amount of promoted generation $Q_a$ is thus decided.

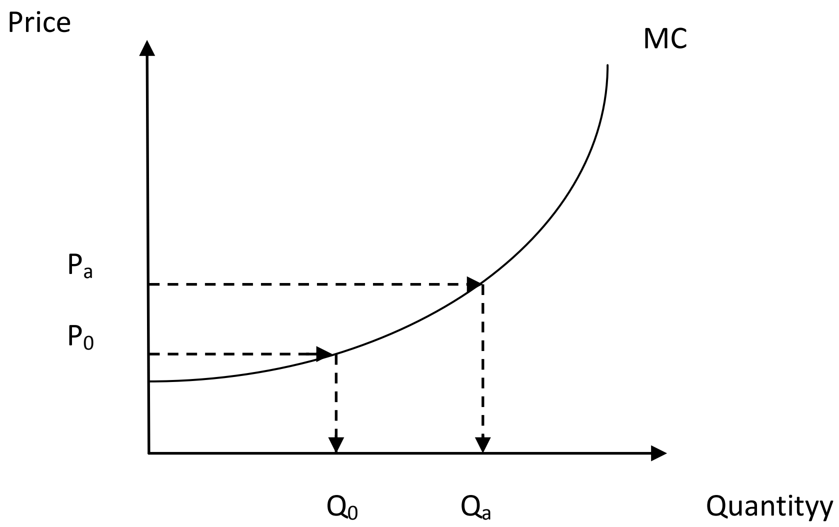


Figure 1: Feed-in System

Ideally $Q_a$ should be equal to the resource potential of the subsidized area. The resource potential concept is price-related, that is to say, it refers to the resource that can be developed within a reasonable price. A too low tariff may be ineffective in exploiting the resource potential, while a too high tariff will result in promotion of poor quality resources and thus higher financial burdens on the electricity consumers. However, in practice the marginal cost curve of green electricity production and the resource potential are generally not known to the policymakers, so the design of a proper price must be based on proper estimates and a good knowledge of the cost structure of the industry, including both the capital cost and operating cost.

In some feed-in systems, generators are not guaranteed the whole tariff, but only a premium above the wholesale market price $P_0$. Generators will have to sell their electricity in the wholesale market, and therefore have more incentives to adjust themselves to the fluctuation of the market demand. The theoretical mechanism of this premium system can also be explained in the above graph, with ($P_a$ – $P_0$) equal to the premium level.

## 2.2 Tradable Green Certificate

The tradable green certificate system is another very popular type of scheme to stimulate the penetration of green electricity. Under this scheme registered producers of green electricity receive a certificate for each unit of electricity produced from unconventional sources. They are responsible to market their own electricity, and usually only the electricity that is put on the grid can be entitled to green certificates. Green certificates can be sold or traded, which becomes a second source of income for the generators, an extra compensation for their generation of renewable electricity. In most of the systems the demand for certificates is from the retailers. The regulators design an obligatory quota for them, requiring them to supply a certain percentage of electricity from green sources. The compliance of the obligation is through submitting the required amount of green certificates, which can either be self produced by the utility, or obtained through the certificate market. Incompliance of the quota will be charged a penalty. A strict penalty system is an important factor for the effectiveness of the scheme.

In a green certificate system, the market demand for green electricity is pre-determined by the regulators and the price will be determined by the market. This is exactly the opposite process to the feed-in system. In the following graph $Q_0$ is the quantity of the green electricity which is already profitable before the introduction of the certificate system, and $P_0$ is the price of wholesale electricity. The certificate system raised the market demand for green electricity from $Q_0$ to $Q_a$. Under a well-functioning penalty system, the quota will be met and the total remuneration for each unit of green electricity will be theoretically equal to the marginal cost of producing green electricity at this demand. The difference of the total remuneration and the wholesale electricity price is the theoretical price of the green certificates.

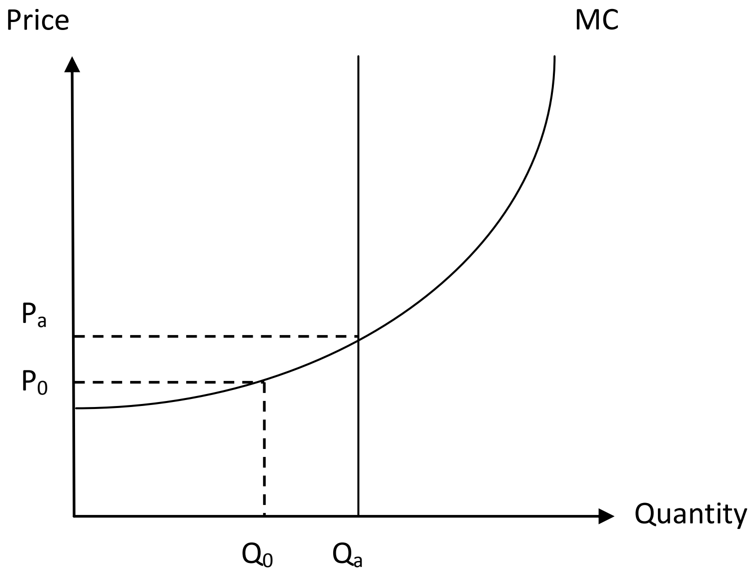


Figure 2: Tradable Green Certificate System

The key question in designing a good green certificate system lies on a good estimate of the resource potential of the country. In the long term the development of the industry will be limited to the level of the mandated quota, because the extra development over the quota will not be able to receive any subsidy. Therefore, a too low quota may limit a country's resource development. Conversely, if the quota is set too high, it will also lead to high incompliance rates. More expensive sites will be developed in order to meet the target, which imposes heavy financial burdens on the consumers. As the marginal cost curve of the industry and the resource potential of the country can hardly be accurately measured, a good estimate and a flexible adjustment system of the quota becomes a critical factor for the success of a TGC system.

## 2.3 Impact of Technological Change

When looking at the mechanisms of the FIT and TGC systems, it is also interesting to study the effects of the external factors. One of the key factors is the long-term technological change which is likely to happen in the renewable industry. As the support schemes are often guaranteed for a long period, the cost reduction brought by technological change is a factor that cannot be ignored. FIT and TGC will experience different impacts from a technological change. Under a FIT system a technology improvement will bring in more green capacity installations, while under a TGC system it will lead to a reduction in the certificate price.

A technological improvement will shift the marginal production cost curve of green electricity rightwards. Under a FIT as the tariff level is still fixed at $P_1$, total output will increase from $Q_0$ to $Q_a$. Policymakers can either keep the output growing, or reduce the tariff level accordingly. Usually in a FIT system the tariff will decrease over time to adjust for the technological change. Under a TGC system the output will stay at $Q_0$ which is the quota level, but the shift of the marginal production cost curve will bring down the certificate price from $P_1$ to $P_2$. Hence the cost of the TGC system will be reduced. The regulators can either keep the reduced quota cost at the same output or increase the quota in order to stimulate more development.

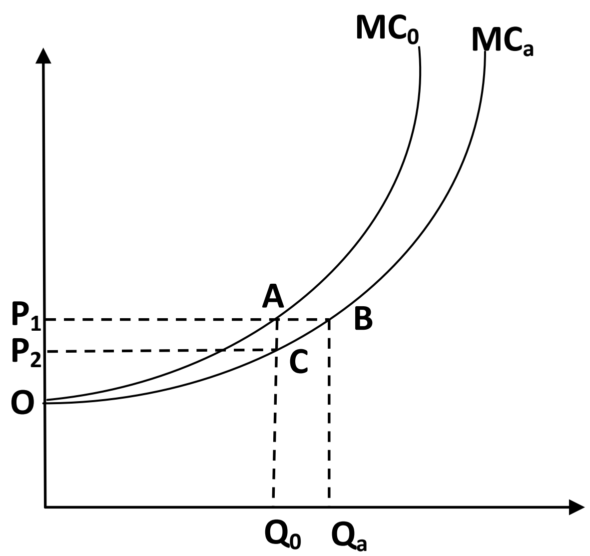


Figure 3: Impacts of Technology Improvement on FIT and TGC

The effects of technological change therefore show the different focus of the two systems. The FIT system has a higher focus on capacity growth, while the TGC system lays more emphasis on cost control.

# 3. Introduction to Wind Power Economics

In this thesis the wind power industry is used as an example to look at the renewable support schemes of different nations. An elaboration on the economics of wind power is presented in this chapter for an introductory purpose. The discussion mainly focuses on the cost structure of the industry, which is the most relevant for the support policies to be discussed in the following chapters.

Upfront investment cost is dominant in the cost composition of the industry. Capital cost accounts for as much as 80% of the total cost of a wind project over its lifespan, which is about 20 years. Capital cost includes the installation of the wind turbine (the turbine and foundation), as well as grid connection and other cost. Variable cost, mainly operation and maintenance cost, accounts for only about 20% in the total cost composition.

The capital cost of a wind project has been increasing rapidly in recent years, after a steady reduction of more than two decades. The average installation cost in the US has increased to $ 2,120 /kW in 2009, which represents an increase of 63% compared to the level of 2003(Wiser and Bolinger, 2009). This increase of the installation cost has a substantial effect on the average generation cost of the wind-based electricity. It means that the projects installed in 2009 will be about 50% more costly than those installed several years ago. The reason for the significant cost increase is the growing prices of the raw materials used in the construction, such as steel, copper and aluminum. For instance, the copper price increased by over 200% from 2004 to 2008, while the aluminum price grew by more than 60% during the same period. The installation cost of wind projects is highly related to the commodity prices. The average installation cost in 2010 may become lower because the material prices came down in 2009, but it is expected to grow again with the recovery of the metal market.

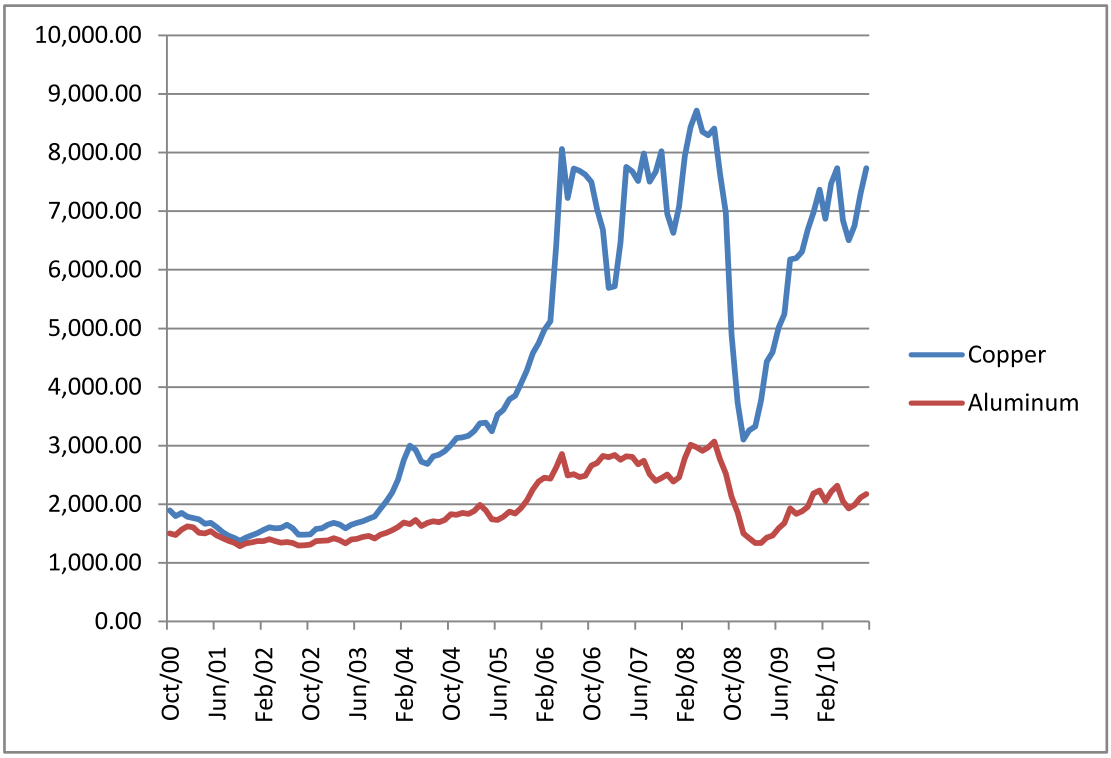


Figure 4: Monthly Prices of Copper and Aluminum, 2000 – 2010 (US Dollars per Metric Ton) Source: indexmundi.com / commodities

The grid connection is also a major cost component. The connection cost for the generators depends on the regulatory framework of different countries. In some countries it is partly or fully covered by the transmission network operators; in others the project developers have to be responsible for all the connection cost and possible cost of the upgrade of the grid.

Blanco (2009) has conducted an estimate of the cost of the wind projects in Europe. According to his studies, the wind turbine accounts for about 71% of the total capital cost while grid connection contributes to about 12%. The other 17% is comprised of other capital cost. The same research has also estimated a variable cost (mainly O&M cost) of about €15 / MWh, which comprises about 10-20% of the total cost over the entire life of the project. In total the author measures the onshore wind cost at about €45–87 / MWh, but it is based on the average installation cost in 2007 at about €1250 / kW. In 2009 the installation cost has been 30% higher so the cost will also increase considerably.

The fact that the upfront investment cost is dominant in the cost structure has a profound implication for the industry. As a developer needs to pay 80% of the total investment when the wind farm is built, capital access and investment risk have become important issues for regulators when designing support policies. The feed-in system has advantages in stimulating investments. It offers a more stable subsidy and usually high repayment in the first several years. Germany is a good example in this aspect, which is discussed in the following chapter. Its FIT scheme lasts for 20 years and in the first 5 years a higher tariff is guaranteed. This provides an early compensation of the investment cost and a reduction of investment risk. The certificate price of the TGC is entirely determined by the market. If we take the capital cost into consideration and introduce a discount rate, the compensation from the certificate market in the late years of the project can only have symbolic effects. In this sense, the TGC system is not very favorable for high fixed cost technologies like wind power; technologies with higher variable cost may get more benefit from it.

The quality of the wind resources is the most important factor that differentiates the generation cost of different sites. We evaluate the quality of wind resources by an indicator called capacity factor. The capacity factor is defined as the average power production of a wind plant, relative to rated installed capacity (TradeWind, 2009). For instance, if a power plant of 100MW generates 600 MWh of electricity a day, the capacity factor will be 25% (600/2400). Good wind resources can usually record a yearly average capacity factor of about 25%, while in some excellent resources it can be higher than 40%. In these good sites the annual output is much higher and average cost can be considerably lower.

Offshore wind power is currently a bit more expensive than onshore wind. The wind turbine and foundation used in the sea have a higher cost, and it is costly to build transmission network to connect the offshore wind farm. The above-mentioned research estimates a cost range of €60 – 110 / MWh (Blanco, 2009). Currently there is only limited offshore wind development in the world, but in the long run it can be a promising area with more mature technology available. This thesis mainly focuses on the discussion of onshore wind power because it is more comparable among the selected countries.

# 4. Country Case Studies

In this chapter a study on the cases of four countries is presented with a focus on the effectiveness and efficiency of the renewable support schemes adopted by the countries. The analysis uses the development of wind energy as a starting point to discuss several key aspects of the countries' policies. An additional look on the promotion of other renewable energy sources is included in the diversity aspect at the end of each country analysis. The following aspects form the structure of the country analysis:

- **Capacity growth:** the capacity growth is the most direct objective of most promotion systems. An overview of the diffusion of the wind capacity is given to explore whether the system has successfully fostered the growth;

- **Resource quality:** the resource quality is an important factor of a country's ability in developing its wind energy. It should be taken into consideration in order to evaluate whether the policy has well explored the resource potential of the country;

- **Target compliance:** the extent of efforts in developing new capacity is highly influenced by the target set by the regulators. An examination of the countries' target compliance can reveal the ability of the system in meeting the targets;

- **Price:** the cost efficiency of the system in promoting renewable generations is a critical factor considered by the policymakers. A comparison of the additional cost incurred by using different systems can help to measure whether the cost of developing wind energy has become too high.

- **Risk:** the level of risks that the renewable generators are exposed to depends crucially on the choice of the support systems. A system that reduces investment risks more effectively would be favored by the new investment decision-making.

- **Diversity:** an overview of the promotion policies on other renewable sources is provided to discuss whether the country's system has aimed to promote a diversified renewable energy mix within the country.

## 4.1 Germany

### Country Overview

- **Electricity Market**

Germany has an electricity generation mix consisting of about 60% from the conventional thermal power source (about 47% from coal and 13% from natural gas) and 40% from the emission-free sources. Nuclear source covers about 22%，wind power covers about 7% and biomass-based power contributes about 5%. The rest is mainly contributed by hydropower and solar power.

The Germany's wholesale electricity market is dominated by the bilateral over-the-counter trading. Besides, the European Energy Exchange (EEX), based in Leipzig, has been growing in recent years and about 20% of the electricity consumed in the EEX area is traded through this day-ahead market. There is not a balancing market in EEX. The major German grid operators buy these services at auction.

Germany is currently using a uniform pricing structure. The transmission constraints are not explicitly reflected through economic signals. Some researchers have proposed a nodal pricing restructure to better handle the transmission bottleneck (Leuthold et al, 2008).

The distributed generators in Germany only pay a shallow connection cost. A shallow charge means that the generators only need to pay the connection cost to the nearest network point. The costs of reinforcing the system beyond the connection assets are borne by the network operators and recovered through grid charges. (Oko-Institut, 2004)

The German electricity market has a high degree of concentration. The four major companies control over 80% of the country's generation capacity, which may lead to market power problems. Some researchers (Musgens, 2006; Schwarz et al, 2007, Weight and Hirschhausen, 2006) have quantified the market power existing in the German wholesale market and concluded that the degree of market power is high.

- **Resource Quality**

In Germany the average wind speed is at a relatively low level compared to the other countries that we discuss. In 2009 Germany recorded an industrial capacity factor of 16.8%, which is close to the average level of the last five years. A comparison of the capacity factor among different countries is given in the following sections.

Besides the reason of having a less favorable wind resource, the lower capacity factor in Germany may also be attributed to the stepped feature of the German FIT policy, which is elaborated in the rest of this chapter. The policy provides stimulus for the investments on the wind sites with less favorable wind conditions by guaranteeing a higher tariff. With those installations the average yield per MW capacity is hence reduced and leads to a lower capacity factor.

- **Capacity Growth**

The wind power generation has achieved steady growth in Germany during the last decade. The country has rapidly emerged as the leading wind power player in the EU countries in terms of installed capacity and power generation. The installed capacity has increased from about 4 GW in 2000 to 25.8 GW in 2009, making Germany the third place in the world only after the US and China. The wind generated electricity amounted to 38 TWh in 2009, a year in which the wind condition was below average, accounting for about 7% of the country's total power consumption (GWEC, 2009).

**Scheme Mechanism**

The strong growth can be largely attributed to the carefully-designed feed-in tariff system. Before 2000, wind power generators were remunerated by the Electricity Feed-in Act introduced in 1991. The Act guaranteed the mandatory access to the network for wind power, and required the grid operators to pay 80% of the average retail electricity price as a FIT, until the proportion of renewable generated electricity has reached 5% of the total supplied electricity by the utility. The policy was later under great debate due to its unbalanced impacts on the grid operators, because higher financial pressure was imposed on the operators in the regions with rich wind generations. Besides, as the FIT was related to the retail price, power generators had to face market fluctuation and some of them were not satisfied (Ragwitz and Huber, 2005).

In 2000 the Renewable Energy Act (Erneuerbare Energien-Gesetz, **EEG**) was enacted to replace the former policy, and remains as the main support policy at present. Several changes have been made under EEG:

- Feed-in tariff is no longer related to the market price but given as a fixed amount.
- A FIT is guaranteed for each generator for 20 years.
- The FIT is divided among all the grid operators and later socialized.
- The 5% requirement of renewable shares is abolished.

The following two key features in the design of the EEG scheme have a significant influence on the well-functioning of the system: a digression tariff structure and a site-differentiated tariff design.

A digression tariff structure refers to a system in which the payments to the wind energy developers decline over time depending on the year of the beginning of the project. For instance, a project starting operation in year 2000 will receive an initial FIT higher than another one starting in 2001. The rate of decrease varies among technologies, with a faster rate of digression for more mature technologies. For wind power, the remuneration started at €70/MWh in 2000 and decreased by 1.5% every year for the new installed capacity. The purpose of this digression tariff design is to provide incentives for cost reduction over time. The rate of digression has to well match the technology learning curve. In 2004 the starting tariff was increased to €87/MWh but the rate of digression was also increased to 2%. In the newly updated version of EEG 2009, the starting tariff for wind-based electricity was increased to €92/MWh to adjust for inflation and the rate of digression was reduced to 1%.

Another important design is to make the FIT site-specific, which is often referred to as being "stepped" (Ragwitz and Huber, 2005). Under the 20 years time frame of the subsidy, the initial tariff is guaranteed for 5 years. This initial tariff is substantially higher than the reduced tariff which will be received in the rest years. The initial tariff is set higher in order to compensate for the high upfront cost in the investment stage. After the five years period, the wind power generators are evaluated by its average yield and the FIT for the rest 15 years is decided. A site with higher wind energy yield than a certain reference value will receive a reduced tariff in the following years. In the EEG 2004 this reduced tariff was set as €55/MWh. In contrast, the tariff to generators with a lower energy yield, which implies that the wind conditions are less advantageous, will remain at the high tariff for a longer period. The length of the extended period will depend on how windy the sites are (Mitchell et al, 2004).

This site-differentiated design reflects the differences in resource quality, which has a strong implication to the behavior of the wind developers. The policy is particularly important in order to promote the sites with less favorable wind conditions, and it helps to maximize the utilization of the wind resources within the country. If this design is not included in the support scheme, all the wind developers will concentrate on those sites with the highest yield. The overall productivity will be increased and the average cost across the country will be reduced. Nevertheless, many potential wind sites will hence be wasted due to a lower profitability. Furthermore, an over-concentration of wind power on an area will lead to great challenges to the reliability of the regional network. In this sense, the stepped tariff design helps to alleviate the pressure of the grid.

In 2009, the reduced tariff for the sites with good wind conditions after five years operation was set as €50.2/MWh, which represented a 10% reduction from the reduced tariff determined in the EEG 2004. The following table summarizes the tariff levels in the three EEG schemes.

Table 1: Tariff Level in the Three EEG Schemes in Germany

| | **EEG 2000** | **EEG 2004** | **EEG 2009** |
|---|---|---|---|
| **Initial Tariff** | €70/MWh | €87/MWh | €92/MWh |
| **Digression Rate** | 1.5% | 2% | 1% |
| **Reduced Tariff** | | €55/MWh | €50.2/MWh |

**Target Compliance**

One of the criteria to assess the success of a support scheme is whether the growth of the promoted energy source can reach the target set by the regulators. Germany has a long-term strategy for developing renewable energy, which can be reflected in the long time frame in the FIT setting – every generator is guaranteed a FIT for 20 years. The target share for the renewables in Germany's electricity consumption was set as at least 12.5% in 2010 and at least 20% in 2020. The target in 2010 was already met in 2007, with the renewable-generated electricity taking up 15.1% of the total consumption and the wind power contributing to 7% (GWEC, 2007). The EEG did not specify a separate target for wind power capacity installations and electricity generation, but the strong growth of both aspects has shown the success of the policy in promoting the technology.

**Price**

The price of promoting wind energy is a crucial topic as all the cost will be socialized and borne by consumers. In a FIT scheme it is simply decided by the level of the FIT.

In Germany the compensation level for the wind power developers is €92/MWh for the initial five years for the projects built in 2009. The initial compensation level decreases by 1% each year for the projects developed later than 2009, until there is a new version of EEG released. For the last 15 years those sites with good wind conditions will receive a reduced tariff of €50.2/MWh while the other sites can receive the initial tariff for a relatively longer period to compensate for the disadvantages of the resources they are operating on.

If we assume that a wind project has a similar yield every year, over the 20 years FIT period the average compensation for each MWh of electricity generated by a good wind site will be about €60 / MWh, given by the EEG 2009 level.[1] The average price in the EEG 2004 is about €63 / MWh. If we consider from an investment perspective, we can calculate the net present value of the FIT compensations in each year and take an arithmetic average. In this way we will get the average NPV of the compensation for every MWh of wind power generation. This thesis aims at providing a rough comparison among the compensation levels of different systems, so here we do not discuss a specific discount rate for the German market. Instead a sensitivity analysis is conducted through assuming the discount rate at 5%, 6%, 7% and 8% respectively, which are the discounts rates that are normally used in the wind industry investment analysis. The result of the sensitivity analysis is shown as follows:

Table 2: The Average NPV of the FIT Compensation at the EEG 2009 Standard

| **Discount Rate** | **5%** | **6%** | **7%** | **8%** |
|---|---|---|---|---|
| **Average NPV of the FIT per MWh over 20 years** | €40.3/MWh | €37.6/MWh | €35.2/MWh | €33/MWh |

[1] Calculated through taking an average of the FIT over 20 years, with the FIT in the first five years at € 92/MWh and in the last 15 years at € 50.2/MWh.

A comparison on the prices between countries is provided in the later sections.

**Risk**

The inherent uncertainty of a support scheme is also an issue concerned by many wind developers. A stable investment environment with a long-term guaranteed compensation will greatly reduce the risk for the wind developers, who need to face a high upfront cost in project development.

The EEG has a strong implication for the security of the wind power investments. A fixed tariff is guaranteed for a very long period, and all the electricity generated will have priority access to the grid. Under such a system the generators will not be involved any price or quantity risk. The price has no volatility, and all generated electricity can be sold at the same price even when the demand is low. The wind developers also do not need to consider any "quality risk". The priority access policy protects them from the competition of the more reliable energy sources.

In an investment climate with significantly lower risk, the risk premium required by the investors will be reduced. The reduced investment risk is one of the essential reasons for the rapid development of renewables in Germany.

However, the priority access of wind power provides challenges to balance fluctuating power feed-in from this inherently variable power source, which is an important reason why the German regulators try to prevent an over-concentration of the projects in one region. The FIT system does not provide sufficient incentives for wind developers to provide reliable output or adjust quantity when the demand fluctuates. The plants have no awareness of the balancing of the system, which has brought negative effects of the integration of the generation to the grid (Mitchell et al, 2004). The extra balancing cost caused is transferred to the consumers, which increases the total consumer cost.

Some improvements are needed in the current system to enhance the integration of the wind-based electricity to the grid. One key issue is to match as much as possible the generation and distribution of wind energy to the actual demand. Some solutions have already been proposed by some researchers, such as charging a use of system (UoS) fee to the generators and differentiate the UoS charge according to the time of use and the connection voltage level. Less UoS should be charged at the production during the peak time and the connection directly at low voltage levels (Frias et al, 2009). If the country does not want to increase financial pressure to the generators (at present in Germany UoS is only to end users), the incentive can also be made as a form of extra bonus to those who adjust production according to the demand.

**Diversity**

Besides the promotion of wind energy, it is also interesting to take a brief look at whether the support scheme is designed to promote a diversity of a country's energy mix. The EEG is designed for all kinds of renewable energy and the level of the feed-in tariff is depending on the cost of different technologies and resources. For instance, the small scale photovoltaic generators (<30 kW) receive €430/MWh in the EEG 2009, which is about seven times as much as the wind developers receive. As for the wind tariff, all the other tariff designs have the characteristics of being digressed and site-differentiated.

The following table briefly summarizes the tariff level for the main sources of renewable energy. The differentiation of FITs by technologies is a critical factor contributing to the rapid development of various renewable sources in Germany. Germany is the leading photovoltaic market in the world, with the highest installations (6.5 GW) in 2009. The country also has the highest biogas power capacity in the world (3.6 GW) and the second highest proportion of biomass power (5.9 GW), only second to the United States. The state's renewable energy strategy aims to achieve a diversified energy portfolio by utilizing all the available resources. The FIT system is essential to reach this goal.

Table 3: Tariff Level for Different Renewable Sources in EEG 2009(€/MWh)

| Sources | Tariff | | | |
|---|---|---|---|---|
| **Onshore Wind** | First 5 years | | Last 15 years | |
| | 92 | | 50.2 | |
| **Offshore Wind** | First 12 years | | Last 8 years | |
| | 130 | | 35 | |
| **Biomass** | <0.15 MW | 0.15 – 0.5 MW | 0.5 – 5MW | >5MW |
| | 116.7 | 91.8 | 82.9 | 77.9 |
| **Small Hydro** | <0.5 MW | 0.5 – 2MW | 2 – 5MW | |
| | 126.7 | 86.5 | 76.5 | |
| **Solar** | < 30 kW | 30 – 100 kW | 0.1 – 1 MW | > 1MW |
| | 430.1 | 409.1 | 395.8 | 330 |

## 4.2 United Kingdom

**Country Overview**

- **Electricity Market**

The electricity generation in the UK relies still mainly on the conventional thermal sources, with coal taking up about 35% and natural gas about 42%. Nuclear generation contributes about 16%. Concerning the renewable sources, about 5% of the total generation is from hydropower, while the shares of the non-hydro renewable sources are rather limited.

The UK's wholesale market is organized by the BETTA, British Electricity Trading and Transmission Agreement. Under the BETTA the majority of electricity is traded bilaterally either OTC or through brokers between generators and retailers. There is not a central dispatch by the system operator; the generators self dispatch and trade on a voluntary basis. Imbalances between contract and physical positions are managed through a short-term balancing market. The market participants submit bids in the balancing market and the cheapest bids are picked to balance the system. The participants causing the imbalance are held financially responsible.

The BETTA market is based on a single-price structure. Only one “spot price” is determined in the balancing market, and congestion is therefore not explicitly priced. Instead, the country imposes a locational transmission network charge (which accounts for roughly 25% of the total network charge) on both the generators and the consumers to signal the importance of the location. (Frontier Economics, 2009).

The power producers in the UK have to pay a shallowish charge to cover connection cost. A shallowish charge means that the generators need to pay for the cost of connecting the network to the nearest point and the proportional use of grid infrastructure reinforcements at the distribution level (Cali et al, 2009).

In terms of the market structure, the largest electricity producer in the UK takes up a market share of about 15%. There are a few large producers of similar size, such as Npower (owned by RWE), PowerGen (owned by E.ON) and EDF. The regulator of the UK electricity market, Ofgem, is concerned that the UK market is vulnerable to abuse of market power (Ofgem, 2009), both when there are constraints on the transmission system or more generally at the time of system tightness. The Ofgem’s report shows that this vulnerability has increased over the past few years and is likely to increase further.

- **Resource Quality**

The UK in fact enjoys some of the windiest areas in Europe (REA, 2009). Compared to Germany, the wind resources in the UK are more favorable. The average wind speed is constantly higher and therefore generates a higher output. A short comparison of the capacity factor of the UK and Germany during 2002 and 2007 has been calculated in Table 4, from which it can be seen clearly that the capacity factor in the UK is considerably higher than in Germany. This can be attributed to the better wind resources that the UK has, as well as the fact that Germany has been extending deployment to the wind sites with less favorable conditions because of the incentives provided by the stepped tariff design in the FIT scheme. The higher generation efficiency implies that the actual average generation cost is lower in the UK, in contrast to the situation that a higher total cost is brought by the Renewable Obligations Certificate scheme, which is discussed in the price section.

Table 4: Capacity factors in the UK and Germany 2002-2007

| | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** |
|---|---|---|---|---|---|---|
| **The UK** | 0.26 | 0.23 | 0.25 | 0.25 | 0.25 | 0.25 |
| **Germany** | 0.15 | 0.15 | 0.18 | 0.17 | 0.17 | 0.20 |

Source: EU Energy in Figures 2010

- **Capacity Growth**

The United Kingdom is the eighth largest nation in terms of total installed wind capacity in the world in 2009. In Europe it ranks number five after Germany, Spain, Italy and France. Compared to the other big countries in Europe, the growth of renewable generated electricity in the UK is not very fast. In this section the data of Germany is used for a brief comparison with the UK.

The total installed capacity in the UK increased by about 3.5 GW from 2002 to 2009. In the same period a new capacity of about 14 GW was built in Germany. Figure 1 compares the growth of wind power capacity in the UK and Germany. In 2008 the onshore wind capacity in the UK generated about 5.8 TWh of electricity, contributing to 1.7% of the UK's total electricity consumption (DECC, 2009). Considering the fact that the UK is host to some of the best wind resources in Europe, the nation should have a great potential to reach a higher penetration level (GWEC, 2009).

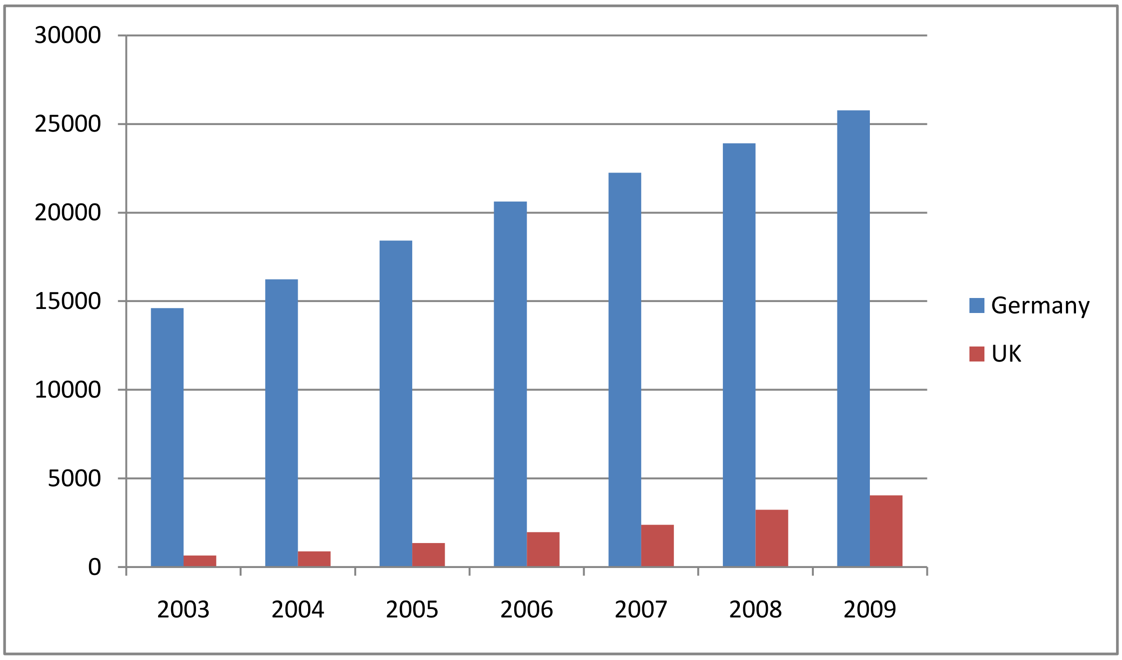

Figure 5: Total Installed Capacity in Germany and UK (2003-2009, MW)

**Scheme Mechanism**

In the UK, a tradable green certificate market was introduced in 2002 to promote renewable energy technologies. The new Renewable Obligations Certificate policy replaced the NFFO (Non-Fossil Fuels Obligation), which was a tendering system in effect since 1990. The ROC policy intended to create a market-based incentive to promote the growth of renewable energy while minimizing the cost transferred to the society.

Under the ROC framework it is the retailers' obligation to purchase a certain percentage of ROCs corresponding to a share of the total electricity delivered. The initial share in 2002 was set at 3% and the target was to raise it to 10.4% in 2010-2011. ROCs are purchased from the licensed renewable generators who get one ROC from every MWh of generation. The renewable certificates can be traded among the retailers. In the ROC system, the renewable generators are responsible to market the electricity generated. They thus have two income sources from their generation: the sale of the generated electricity and the sale of the ROCs.

If the retailers do not fulfill their obligations through collecting enough ROCs, they need to pay a buy-out fee for every MWh of electricity delivered until the target obligation share has been reached. The buy-out penalty in 2002 was decided as £30 / MWh and adjusted annually to inflation. All buy-out payments are redistributed among the retailers in proportion to the number of ROCs they have presented, so the buy-out penalty compensates those retailers who collect ROCs. The existence of the buy-out mechanism increases the complexity of the system. It is easy to understand that when the ROC market is oversupplied, the buy-out fee will act as a price ceiling; on the other hand, it serves as a price floor when the market is undersupplied. When the electricity generated from renewable sources cannot meet the demand of the retailers, the value of ROC will go above the £30 floor. This is because the buy-out penalty is finally recycled to the ones who present ROCs, which means buying the ROCs can bring an additional income. This additional income will therefore add to the £30 floor price and lead to a higher ROC value (Hartnell, 2003).

A numerical example shows how the system works:

The ROC target of 2007 is 6.7% and the actual generation of renewable electricity is 5.1% of the total generated electricity. The buy-out price in 2007 is £33.24/MWh (REA, 2009) which will be the floor price. Since the RES electricity supply can only meet the demand by 76% (0.76 = 5.1/6.7), there is 24% of the quotas needed to be met by buy-out penalty and the total penalty submitted is £8/MWh (33.24 * 0.24 = 7.97). When this penalty is recycled into the retailers who provide ROCs, by supplying one ROC a retailer will get £10.5/MWh back. (7.97/0.76 = 10.5) This recycled value will thus raise the value of the ROCs as well as the price, and therefore the price of ROC in theory will be £43.74/MWh if only 76% of the demand for certificates is met and the buy-out price is £33.24/MWh. This theoretical price will then be influenced by the market expectation and the actual trading process.

**Target Compliance**

The development of the UK renewable energy market is unsatisfactory after the implementation of the ROC policy. Despite the fact that the wind resources in the UK are concluded to be more advantageous with higher average wind speed and more potential sites, the wind diffusion level is not very high.

The ROC scheme is also not very effective in meeting the obligation target. The target set in 2003 was to reach 10.4% of the electricity generation from renewable sources in 2010. Recent data shows that in 2007 the share is 5.1%, representing a limited increase from 2.7% in 2000. A discrepancy can be observed between the RO target and the actual share of generation over the years that the RO was implemented, as the following figure illustrates.

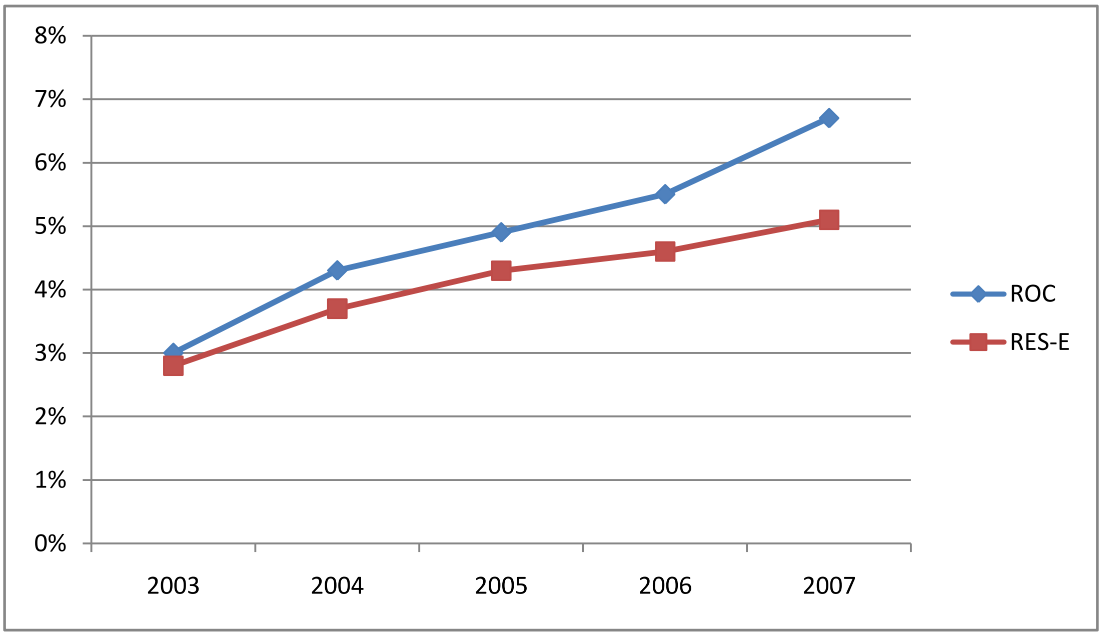


Figure 6: RO Targets and the Actual Share of RES-Electricity 2003 – 2007

The ineffective compliance of the target can possibly be attributed to two factors:

- Flaws in the design of the RO system
- High market entry barrier

From the explanation of the pricing mechanism of the ROCs, it is clear that the price in the ROC market is determined by the difference of the supply and demand of

ROCs. Under the RO scheme the demand depends highly on the given target, which enables the renewable generators to influence the price. A higher shortfall of supply compared to the demand will lead to a higher price per unit, due to the existence of the buy-out penalty. The renewable generators are therefore better remunerated. However, if the obligation target is met, the ROC price will crash. Under such a mechanism, the existing renewable generators have incentives to keep the market undersupplied in order to maintain the ROC price.

If the market entry barrier is small, this mechanism will not cause any problem. Even though the existing renewable generators can control the supply to get a higher profit, more producers will enter the market to meet the demand and reduce the price. However, this does not apply to the UK's case. In the UK, more than 70% of the wind capacity is directly or indirectly owned by the four major electricity suppliers who provide electricity for the whole country (Toke, 2005). These suppliers, at the same time, are often the investors of new installations. They have both incentives and market power to protect the existing projects from the crash of ROC price. On the contrary, if the compliance is delayed, the wind generators can benefit from a higher ROC price, while the extra cost paid by the main retailers will be recovered by the recycled buy-out penalty. The total revenue of these retailers is increased. Under such a situation, it is unlikely that they will allow the target to be met. Instead, they will exert their influences on the market to create barriers to those independent generators which don't belong to the main retailers.

The entry barrier problem is further compounded by the fact that new market participants need to face a large upfront investment and high uncertainty caused by the RO scheme, which is elaborated in the risk section.

**Price**

In addition to keeping the market undersupplied, the flaw in the ROC mechanism also increases the cost of promoting renewable-generated electricity. The ROC scheme is supposed to have advantages in bringing down renewable prices. The market-based design aims at triggering competition among the renewable generators and the overall objective is to minimize the social cost of adopting renewable technologies. A well-functioning green certificate market is expected to have lower cost than a FIT scheme which is considered not involving competition among the generators.

However, the price development of the UK ROC market did not provide evidences that the cost of supporting renewable energy have been effectively reduced. The total cost for every MWh of wind-based electricity generated in the UK in 2003 were €96, consisting of both the electricity and the ROC prices. Here we can make a rough comparison with the FIT for wind power in Germany. In 2003 the FIT for the first five years' generation of a project is €77/MWh, while the compensation after the first five years is even much lower. The FIT in Germany increased slightly in the following years, subject to the adjustment to inflation. At the same time, the average cost in the UK for wind-generated electricity stayed in a high level of above €100/MWh. In the period of January to July in 2009 the average cost of one megawatt wind-generated electricity was about €108, in which the cost of ROC was €61 and the electricity price paid to the generators was €47. In the same year the FIT in Germany for the initial 5 years is €92/MWh. The high cost of compensating the renewable generators are due to the high price of ROC in the market, which can be again attributed to the supply and demand imbalance described above. The price of ROC will go up when the obligation target is not fulfilled because the buy-out penalty paid for incompliance will add to the basic value of the ROCs. Since the difference of the RO target and the actual RES electricity supply has been enlarged over the years after 2003, the price of ROCs has become higher and brought up the overall cost.

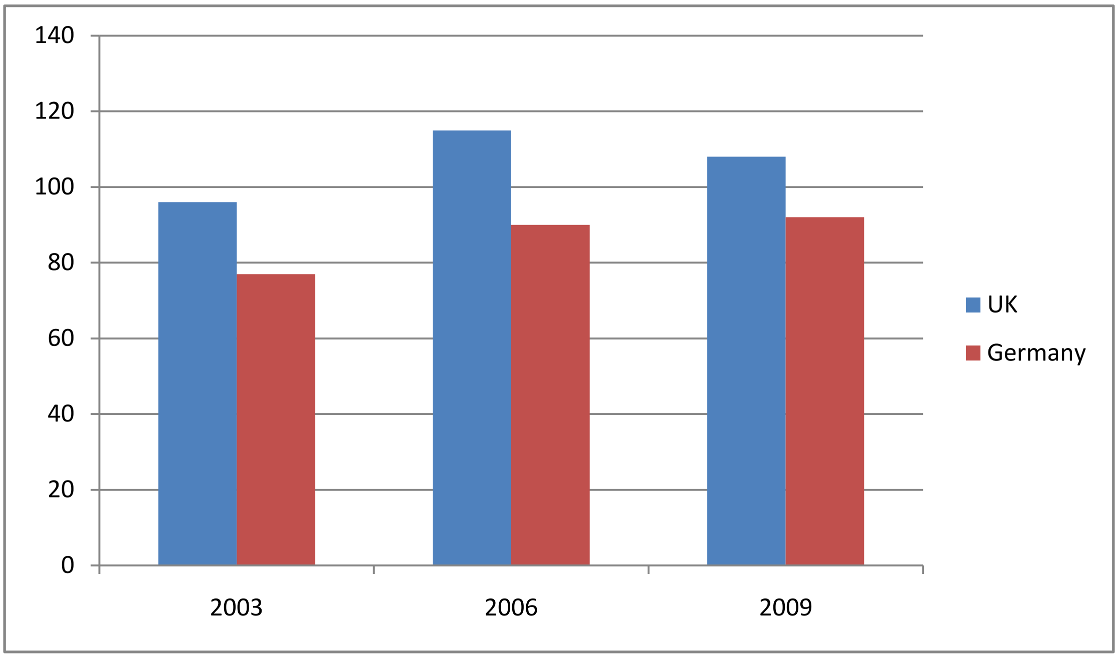


Figure 7: The Compensation Level for the Wind-based Electricity in UK and Germany[2] 2003-2009 (€/MWh) Source: EREF 2006, 2009

**Risk**

The ROC system has been criticized by many researchers for the higher risk it brings to the renewable generators (Mitchell et al, 2004; Rickerson and Grace, 2007; CEC, 2005). There are mainly four types of risks existing in the ROC scheme: price risk, quality risk, quantity risk and regulatory risk.

Under the ROC system, the revenue of the renewable generators will depend on the price volatility of both the electricity market and the green certificate market. A relatively high degree of fluctuation has also been observed in the UK ROC market during the last 8 years (NFPA, 2010). The 3-month average auction price of ROC has ranged from £38/MWh in 2005 to £53/MWh in 2009. The volatility of both markets will create higher price risk to the renewable generators than a simple FIT system. However, so far the problem of a high risk premium is still not obvious in the UK because the overall price level of ROC has been very high compared to the compensation level in other countries and will likely ensure the investments profitable.

[2] The Germany's price is the tariff for the first five years of a project in the EEG systems. The average tariff over the project cycle should be even substantially lower.

The investment risk should be relatively low given such a high ROC price. However, in the future if the amount of wind projects invested becomes higher in the UK power market, the certificate price will be brought down and the price volatility may lead to high uncertainty to the wind developers.

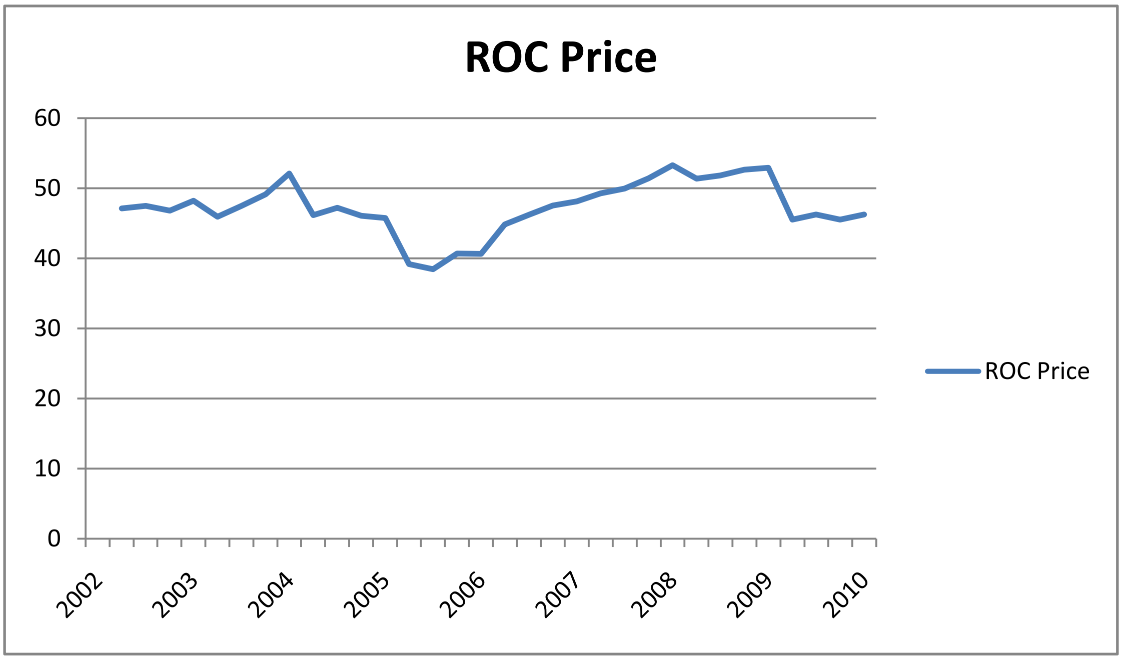


Figure 8: Price Development in the UK ROC Market 2002-2010 (£/MWh) Source: NFPA, 3-month average auction price.

The UK wind developers also need to face a high balancing risk under the RO scheme. In the UK the system operator balances the system. If in a certain hour the renewable generation from a renewable plant is either over or below the planned generation amount, the generator has to pay a penalty as a balancing cost.

The quantity risks in both the power market and the ROC market are also not ignorable. In the power market, the generators may not be able to sell the electricity when the market demand is low; in the ROC market, old projects may not be able to sell all their ROCs because new projects may have a lower cost.

The price, quantity and balancing risk is further compounded by the regulatory risk on the continuation of the RO target. If one RO target is met while there is not a new target released, the price of the ROC will drop significantly which can cause huge risk for the wind developers. All the risks mentioned above will bring uncertainty in return on investments, which creates barriers for the new entrants.

**Diversity**

The ROC scheme implemented since 2002 did not differentiate compensations to different renewable technologies. Given a certain amount of electricity generated, a wind generator will receive the same amount of ROCs as a photovoltaic generator. This implies that the technology with cost advantage will be promoted first until the resource potential is fully developed. Even within one technology, a site with a higher resource quality will be developed in priority. Such design is consistent with the policy's target of meeting the obligations with minimized social cost. However, technologies with higher cost receive little incentives through such system. In the UK, the deployment of relatively expensive sources remains low after the implementation of the ROC scheme. This is quite reasonable and reflects the country's overall energy strategy.

In 2009 this policy was changed in order to pursue a more diversified renewable energy mix. Different technologies receive different amounts of ROCs for every MWh of electricity generated. The table below briefly summarizes the support level. High cost technologies such as photovoltaic, will receive 2 ROCs for every MWh generation. However, this support level is still too low to make PV installations profitable in the UK despite of the current high ROC price.

Table 5: Support Level for Different Renewable Sources in RO 2009 (ROC/MWh)

| | **Onshore Wind** | **Offshore Wind** | **Biomass** | **Small Hydro** | **Solar** |
|---|---|---|---|---|---|
| **ROC** | 1 | 1.25 | 1.5 | 1 | 2 |

Source: REA (2010)

Despite of the low penetration rate in the onshore wind market, the UK is particularly strong in the offshore wind market and is the leading country in the world, though the market itself is not very big (883 MW of installations in 2009). The UK enjoys a high abundance of offshore resources along its coastline and the average capacity factor is more than 35%. A combination of the onshore and offshore wind development may be the emphasis of the UK's long-term renewable strategy.

## 4.3 Texas

**Country Overview**

- **Electricity Market**

The competitive part of the power market in Texas satisfies about 85% of the state's electric load. It is administered by the Electric Reliability Council of Texas (ERCOT), a non-for-profit Independent System Operator (ISO) established to facilitate the efficient use of the electric transmission system for all market participants. There are more than 500 market participants acting different roles in the value chain of the Texas wholesale market.

In 2009 76% of the total generation is from conventional sources. (36% is from coal and 40% is from natural gas.) Concerning the emission-free sources, nuclear power contributes about 15% while wind power has a share of about 7%.

The market structure in Texas was designed to permit an extensive reliance upon bilateral contracts between generators and retailers to reduce consumer exposure to hour-to-hour fluctuation in electricity prices. The ERCOT does not operate a centralized market for power, but instead operate a market for balancing services which has a similar role as a spot market and covers about 5% of the Texas' electricity generation. It also administers day–ahead ancillary services. The Texas regulator imposes price caps in the balancing market and ancillary services to avoid local market power abuses.

Texas' shared network is open access and connecting parties only need to pay shallow connection charges (Baldick, R and Niu, H, 2008).

Before December, 2010 Texas used a zonal congestion management system. Five congestion zones were established to facilitate the use of the transmission system during periods of binding transmission capacity constraints. All the market participants were required to submit their energy schedules to the ERCOT. Every 15 minutes the ERCOT compared the sum of the schedules and its own forecast, and provided balancing and ancillary services. If the submitted schedule resulted in network congestion, the ERCOT would re-dispatch resources (Baldick, R and Niu, H, 2003). The Inter-zonal congestion cost was directly assigned to those who cause congestion. On the contrary, the intra-zonal congestion cost was allocated among all the market participants on a load-ratio share basis.

In order to better assign congestion costs to responsible entities, for a long period the Texas authority has been considering shifting from the zonal design to a nodal design (SUEZ, 2005). In December, 2010 a nodal market is formally implemented in order to facilitate more efficient dispatch and cost allocation across the ERCOT.

Preventing market power abuse is an important task for the Texas regulators. In order to dilute market power, no generator is permitted to control more than 20% of the installed capacity in the ERCOT. But Texas still has relatively high degree of market concentration (the market leader in each zone has a market share of about 50%), though there has not been conclusive evidence that any market participants have abused their market power (Adib and Zarnikau, 2006).

- **Resource Quality**

There are abundant wind resources in West Texas. The average wind speed can reach 8 m/s and some wind developers report a capacity factor of 35% or more. The generation cost in some plants can be less than $30/MWh, which is almost economically comparable with natural gas. The average wind capacity factor in Texas is around 23%, a level quite similar to the UK. The actual resource quality may be even better than is reflected by the capacity factor. Due to the transmission constraints, generation from some sites have to be curtailed, lowering the overall capacity factor (CEE, 2009). The excellent resource quality is the essential factor for the rapid deployment of wind capacity in Texas.

- **Capacity Growth**

The United States has the largest installed wind capacity in the world. In 2009 there was nearly 10 GW of new capacity added and the total capacity reached 35 GW. Wind-generated electricity covers about 2% of the country's total electricity demand in 2009. In the US the tradable green certificate market is the most popular mechanism to promote renewable energy. However, there is not a federal green certificate system so far. The states establish their own TGC schemes. The TGC in the US is often referred as RPS, Renewable Portfolio Standards. Mandatory RPS policies have been created in 29 states and Washington D.C. in 2009 (Wiser et al, 2008).

Due to the fact that the RPS policies in the US vary from state to state, in this paper Texas is chosen as an example to discuss the RPS application in the US. Texas is considered by many researches as one of the most successful examples of promoting renewable energy growth through an RPS system (Wiser et al, 2004; Langniss and Wiser, 2003). The conclusion is made based on the tremendous growth of the installed capacity of renewable generation, especially the wind energy capacity after the implementation of the state's RPS scheme. Texas enjoys outstanding wind resources and most of its renewable generation comes from wind. In 2009 a new capacity of 2292 MW was added and the state is leading in the United States by running a total capacity of 9410 MW. The total electricity generated by wind is 20.6 TWh, representing about 6.9% of the total consumption in the state (ERCOT, 2009).

**Scheme Mechanism**

Texas is one of the first states to enact an RPS in the US. The operation of the Texas certificate market shares many characteristics with the UK ROC market. The scheme covers all the retailers in the competitive market in Texas, which constitutes about 80% of total Texas load. The retailers need to fulfill the RPS requirement by presenting the mandatory quantity of Renewable Energy Certificates (RECs) every year. The renewable generators obtain one REC by generating one MWh of electricity. Similar to the UK system, their revenue stream will come from the sale of both the electricity and the RECs.

The required target of the Texas RPS, different from the ROC in the UK, is described in term of the installed capacity instead of the share of RES-E in total electricity generation. The targeted installed capacity is translated into required electricity generation by regulators every year to set requirements for retailers. The retailers are required to collect RECs in accordance to their share of the state's total electricity sales. The RECs can be traded among generators and retailers and surplus of RECs can be banked for maximum three years. With regard to the penalty for incompliance, it is set as the lesser of \$50/MWh or 200% of mean REC trade value in the compliance period for each missing certificate. \$50/MWh thus acts as a cost cap for the compliance. （Langniss and Wiser, 2003）

The Texas scheme does not include a mechanism like the buy-out penalty in the UK to recycle the penalties back to the retailers. Also, it does not provide priority access for the renewable generators. The wind sites need to compete with the traditional generation facilities in order to get dispatched.

It is important to mention that in addition to the RPS scheme, the Texas wind generators are entitled to another important supportive policy, but from a federal level. It is the production tax credit (PTC) offered by the federal government and eligible in all US states. The PTC is a per-kilowatt-hour tax credit for electricity generated by qualified energy resources and sold by the taxpayer during the taxable year. The latest PTC, approved by the bill signed in 2009, provides \$21/MWh benefit for the first ten years of a wind plant's operation (UCC, 2009). For the generators the PTC works like a fixed premium. The existence of the PTC has a high influence on the mechanism of the RRS system. Suppose the REC quota is set at $Q_a$. Originally the price of the certificate will be theoretically equal to the difference of $P_1$ and O (wholesale electricity price). When the generators are guaranteed a premium A (equal to the difference of $P_1$ and $P_2$), the price of the certificate will be reduced by A and equal to the difference of $P_2$ and O. The larger the premium is, the lower the certificate price will become. The theoretical output will still stay at $Q_a$.

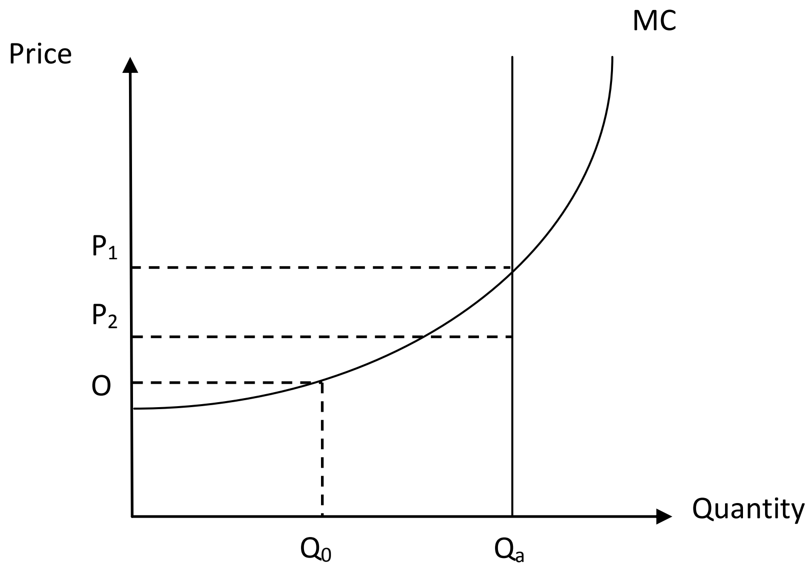


Figure 9: Interaction of the RPS system with the PTC

In some extreme cases, if the premium level is high enough to make the wind generation economically viable, the installed capacity will surpass $Q_a$ and the price of the certificates will become zero. If the regulators want to make the market continue working, they can raise the quota to a higher level in order to get the equilibrium at a point where the marginal cost is higher than the total compensation (wholesale price plus premium).

**Target Compliance**

Texas has experienced significant growth of wind energy which far exceeds the goal set by the Texas RPS. The scheme was established in 1999 and the initial requirement was in Texas Senate Bill 7 to build 2000 MW of new renewable capacity by the end of 2009. This goal was easily achieved in 2005, four years prior to the deadline stipulated in the bill. The quick compliance of the goal can be attributed to the outstanding resources in Texas and the impact of PTC. In contrast to this, the initial goal seemed to be a bit conservative. The required 2000 MW capacity by the RPS scheme, in addition to the 880 MW renewable capacity that Texas already had before 1999, can only satisfy approximately 2% of the electricity consumption of the state in 2009.

The early over compliance of the RPS scheme led to an updated requirement, Texas Senate Bill 20 in 2005, which asked for an expansion of the state's renewable capacity to 5880 MW by 2015. Nevertheless, the updated requirement could hardly be considered as being more ambitious. A capacity of 5880 MW can only generate electricity representing about 3.6% of the total consumption given the 2009 level, not to mention the consumption growth until 2015. The relatively conservative goal is incompatible to the rich resources that Texas has, compared to the estimate by the US Department of Energy that 20% of the US electricity can be provided by wind in 2030. Even compared to other states in the US, the 2015 goal of Texas is quite conservative. California, for instance, requires at least 20% share of the total electricity consumption to be satisfied by renewable sources by 2010 (Bushnell et al, 2007).

The market has acted much more aggressively than the regulators. The goal in 2015 was surpassed in 2008 when the total installed wind capacity reached 7112 MW. The Senate Bill 20 also designed an ultimate goal in 2025 to reach 10,000 MW of capacity but did not stipulate any punishment for incompliance. However, this ultimate goal can generate only 6% of the consumption at a 2009 level, and it will also be met as early as in 2010, 15 years prior to the regulator's projection, provided that the installed wind capacity has reached 9410 MW at the end of 2009 (AWEA, 2009). Figure 5 demonstrates the high degree of discrepancy between the actual growth and the two RPS required quota schemes.

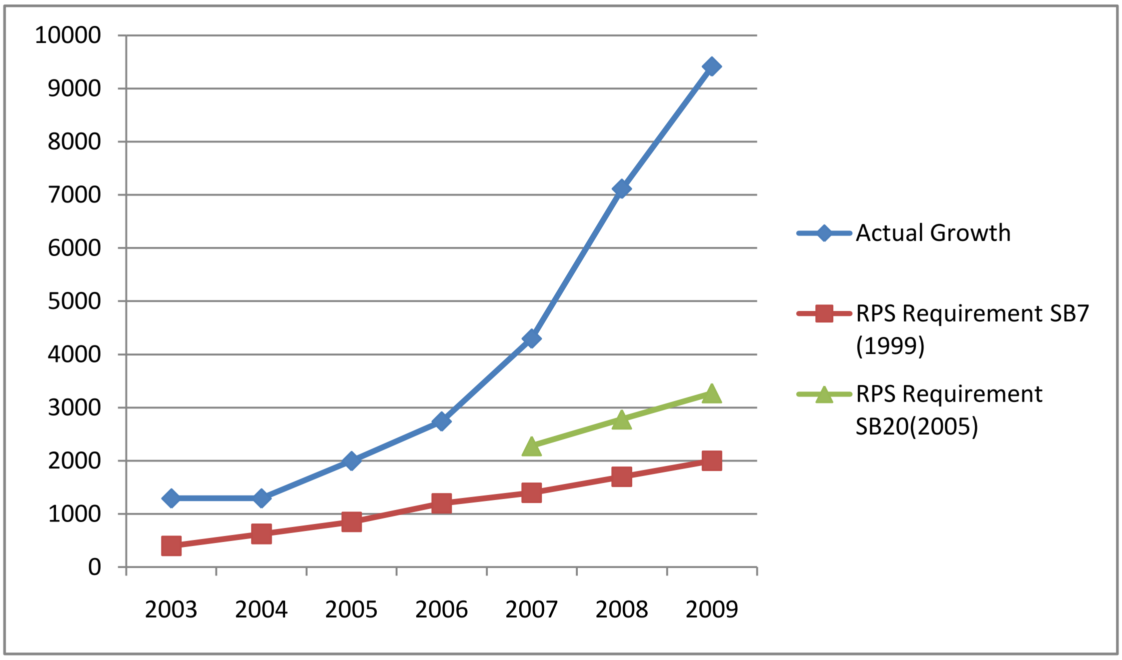


Figure 10: Actual Installed Wind Capacity and Requirement by RPS 2003-2009 (MW)

Source: AWEA (2009), Texas Senate Bill 7 (1999), Senate Bill 20 (2005)

The conservative objective has also created transmission constraints in utilizing the existing wind capacity. Most of the new wind capacity concentrates in West Texas where the wind resources are most productive. However, the utilization of this capacity is curtailed by the development of the transmission capacity. Due to a conservative goal-setting, the long-term planning of transmission capacity construction cannot satisfy the rapid development of wind capacity. The transmission constraints limit the utilization of the new capacity, and the high penetration of wind power also challenges the reliability of the current network. According to a survey done by University of Texas at Austin among the wind project developers，93% of the survey participants considered the timely expansion of transmission capacity to accommodate wind potentials in West Texas as the most important issue in promoting renewable energy in Texas. (CEE, 2009). The limited transmission capacity places the wind developers in a difficult situation. In Texas it can be occasionally found that wind power is sold at negative prices: in order to get dispatched to collect remuneration from the PTC, some wind developers have to submit negative bids in certain hours

**Price**

The average wholesale price of electricity in Texas is relatively high over the recent years at about $70-80/MWh (about €51-58/MWh). The high price is due to the high cost of natural gas, which constitutes 40% of the state's electricity generation (CEE, 2009).

The wind power capacity deployment in Texas has achieved significant progress; however, when reviewing the price development of the REC market, it can be found that the capacity growth is not due to the REC market. The claim that the Texas RPS scheme has stimulated the state's large-scale wind power market development is actually misleading.

After fluctuating between $10 – 12 for a couple of years after 2003-2005, the price of the RECs has been in the downward trend since the first REC quota was met in 2005. During this period the federal PTC was the main factor that was driving the market. The growth of the installed wind capacity tends to rise and fall with the renewal or expiration of the PTC. According to the investigation done by CEE (2009), PTC has been the single most important factor for the market participants when making investment decisions. 86% of the wind generators considered PTC as very important. In the same research only 21% of the generators considered the certificate price as a very important factor.

The market went to clash in 2008 when the second quota in 2015 was met 8 years in advance and no further goal was stipulated. In 2009 every MWh of electricity generated by wind power can only obtain a subsidy of $1.25 for selling a REC. With such a price the RPS scheme is no longer considered a factor in investment decision. The authorities did not propose any update of the quota, which to some extent showed that the regulator gave up the RPS as a means of promoting renewable energy and solely relied on the PTC. The REC price is not likely to go up unless a more ambitious requirement is raised in the near future.

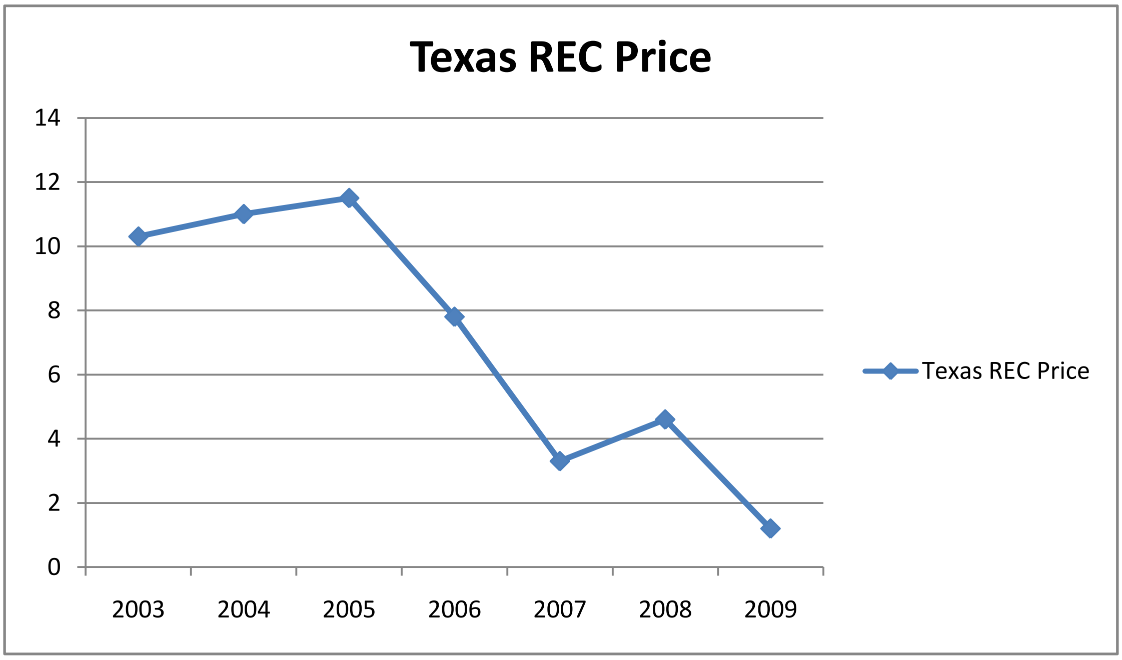


Figure 11: The Development of Texas REC Price 2003-2009 $/MWh

Source: 2008 Wind Technologies Report. Data comes from Evolution Markets and Spectron

In 2009 the installed wind capacity in Texas continued to grow despite of the collapse of the REC market. The PTC has become the only instrument to fuel its growth. The current PTC approved in 2009 is $21/MWh, about 20 times of the level offered by the REC market. This level is enough to make the wind projects profitable given the current scale of the industry. It will be valid until 2012, and whether the wind energy generation will continue to grow will largely depend on the extension of the PTC. Despite the existence of the PTC, Texas does not have a policy to guarantee a long-term investment support, which makes it difficult to sustain the development at a stable level.

On one hand, the Texas market has achieved the goal of the policymakers, as the targets set by them were easily passed. On the other, the Texas certificate market cannot be considered as a successful example of using a TGC scheme to stimulate a large amount of renewable generation. The targets set by the regulators are conservative compared to the development level in Texas today. The RPS scheme only partly contributes to the fulfillment of these two goals (together with the PTC), while most of the market development after 2007 has to be attributed to the PTC policy instead of the certificate market.

A counterargument to the ineffectiveness of the REC market might address that the Texas wind market has achieved rapid development and low price at the same time. Researchers holding this opinion may attribute the low price to the competitiveness brought by the REC market. This argument simply neglects the fact that the collapse of the market is primarily due to the introduction of PTC, instead of a real decrease in wind generation cost. A well-functioning tradable certificate scheme should stimulate competition among the wind generators which reduces the generation cost and the price of certificates. In the Texas case this does not happen. The wind generation cost remains more or less the same, but instead is covered by the PTC policy offered by the state. Therefore it is not appropriate to exaggerate the effectiveness of the Texas REC market.

**Risk**

In a tradable certificate scheme the price uncertainty inherent in both the electricity and certificate market is often one of the essential factors that hinder the capacity deployment. In the early development of the Texas REC market this problem was alleviated by the emergence of long-term contract. Obligated retailers were willing to enter long-term contracts (10-25 years) with wind generators for both the RECs and the associated electricity in the early years of the RPS implementation (Langniss and Wiser, 2003). The long-term contract provides a possibility for the wind projects to receive stable revenue streams for a certain period, and therefore plays a similar role as the FIT system in Germany to reduce investment risk. The only difference is that it is achieved by a market-based mechanism instead of a regulatory intervention.

However, as the REC price has clashed and the current support level from the certificate market is low, it becomes more difficult for the wind developers to enter a long-term contract with a price appropriately reflecting the cost. Without long-term contracts as a means to reduce uncertainty, the new entrants have to face a significant risk in price volatility. The problem is further compounded by the uncertainty about the extension of the federal PTC, which will be decided in 2012. The development of wind will not be able to sustain if there is not a renewal of PTC.

**Diversity**

Before the Senate Bill 20 in 2005, the PRS in Texas did not aim to promote a diversified energy mix. All the renewable sources can be used to fulfill the REC requirement. As a result, wind has emerged as the dominant technology, accounting for 98.5% of the renewable generation. In the SB 20, a target for “non-wind” technologies for Texas was raised to achieve 500 MW by 2015. The 500 MW “non-wind” target also does not differentiate between technologies, so the development will still concentrate on the lowest-cost technology. However, the target is still non-binding so far and there is no penalty for non-compliance. The goal of 500MW by 2015 can only represent 5% of the capacity of wind power in 2009, which can hardly have any significant effects on the Texan energy portfolio.

## 4.4 Denmark

**Country Overview**

- **Electricity Market**

Denmark has 30% of its total electricity production from renewable sources: wind power contributes to about 20% and biomass-based power shares about 10%. Conventional sources take up 70% of the generation mix. The country has 50% of its generation relying on coal-powered plants and about 20% from gas-fired plants.

Western Denmark and Eastern Denmark joined Nord Pool, the Nordic common power market, in 1999 and 2000 respectively. The physical trading in Nord Pool currently covers more than 75% of the electricity consumption in Norway, Sweden, Denmark and Finland. Nord Pool organizes three distinct markets: a physical spot market Elspot, as well as a financial derivative market Eltermin for risk management and speculation and a balancing market Elbas. Besides Eltermin, the market participants can also OTC contract bilaterally.

Elspot is a day-ahead market for physical delivery of electricity. Hourly demand and supply bids are submitted for the next 24 hours and aggregated to generate a system price (clearing price). All electricity is traded at the system price when there are no transmission constraints.

Transmission constraints are handled differently in the Nord Pool countries. In Denmark a zonal pricing method is used. The market is divided into West Denmark and East Denmark with different clearing prices. The renewable generators in Denmark pay a shallow connection charge when connecting to the transmission grid.

The concentration ratio in the Nordic level is quite low, but on a national level it is much higher. In Denmark there are two main generation companies respectively in the two zones. However, researches (Fridolfsson and Tangeras, 2008) show that the Nordic market is fairly close to competitive and there is no clear evidence for market power abuse.

- **Resource Quality**

Denmark also enjoys very high quality of wind resources. The national annual average wind speed is about 6 m/s, and in the North and West parts it is possible to observe strong winds at above 10 m/s in more than 150 days of a year. The capacity factor of Denmark has been staying at about 25% in recent years. It is considerably higher than the years around 2000 when the capacity factor was about 20%. The reason for the increase is that Denmark started to export wind-generated electricity to neighboring countries. In previous years the generation was limited by the transmission constraints and the wind farms could not work at a maximum capacity. As excess wind-based electricity began to be traded, more generation capacity could be utilized and thus raised the capacity factor.

- **Capacity Growth**

Denmark is among the first movers of wind energy and wind power has played a crucial role in its energy mix. The country has experienced some ups and downs in the history of wind development. As early as in 2000, it had already built more than 70% of its total capacity today. However, the wind power industry had almost no growth from 2003 to 2008 due to an insufficient subsidy level. The growth was recollected in 2009, and by the end of the year a capacity of 3, 465 MW has been installed in total. This represents the 10$^{th}$ highest installed capacity in the world. All over the world, Denmark is the country where wind is most widely used. Wind-generated electricity constitutes 20% of its electricity demand while there is also a remarkable amount exported to the neighboring countries (GWEC, 2009).

**Scheme Mechanism**

The development of wind power in Denmark can well reflect the importance of the support scheme. A Feed-in Tariff system was introduced in 1993 as a stimulus for wind's spread in the country. All the wind developers were guaranteed priority access into the network, as well as a FIT from the utilities equal to 85% of the price paid by the end consumers. As the market was not liberated at that time, the electricity price was relatively stable and the compensation level of the FIT was about €80/MWh (Munksgaard and Morthost, 2008). The FIT was a great boost for the wind industry, which helped Denmark to become one of the leading countries in this field in the world.

During the years around 2000 the Danish policymakers considered to change the FIT system into a trading green certificate system due to a political preference of a TGC system at that time. However, the plan was postponed in 2000 as the industry was considered not ready for the new scheme. In 2002 the proposal was postponed indefinitely when the political preference shifted back to the FIT system and when it was clear that a common European certificate market was not possible in the near future (Agnolucci, 2005).

Instead, a feed-in premium policy was adopted in 2001 in a Danish electricity reform aiming at liberalizing the renewable energy market. In the modified policy the support level was substantially reduced. Newly built wind farms no longer received a fixed amount from the utilities; instead, they had to sell the electricity at market price, and were only compensated by an environmental premium of 100 DDK/MWh, about €13/MWh at that time (Lipp, 2007). On the other hand, the old sites could still be covered by a price of €80.5/MWh for the next 10 years operation. The new compensation level was considered to be too low and it could not sustain the development in the industry. The industry almost did not make any progress after a transition period in 2002. During 2003 to 2008 there was only 21 MW of new capacity built, representing about 0.7% of the industry's scale. The market participants used a silent way to prove that the new policy was not appropriate for the industry. It was still too early to expect that the wind industry can be economically competitive.

In 2009 the policy makers finally decided to increase the support level. The environmental premium was increased to about €34 for the first 22000 full load hours of the wind projects. 22000 full load hours is about 2.5 years. Considering a capacity factor of about 25%, the total estimated compensation period is about 10 years. This premium adds on top of the market price which would also be received by the wind developers. The increase of the feed-in premium encouraged a recovery of the industry. 2009 became a turning point for the wind industry and the total installed capacity increased by 10%. Following is a table of the total installed capacity from 2001 to 2009.

Table 6: Installed Wind Capacity: 2001 - 2009 (MW)

| | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|---|---|---|---|
| **Capacity** | 2489 | 2889 | 3115 | 3123 | 3127 | 3135 | 3124 | 3136 | 3465 |

Source: GWEC 2009

A key difference between the feed-in premium in Denmark and the FIT scheme in Germany is that the first one is paid on top of the market price. As a result, the wind developers in Denmark still need to face the price volatility from the market, and adjust the production according to the fluctuation of market demand and supply. It also involves more market competition to the wind developers, as they are responsible for the marketing of their own electricity and need to provide a higher quality and reliability. The feed-in premium system can be considered as an advanced level of the FIT and more suitable for a market where the technology is more mature. The system introduces some degree of uncertainty, but provides incentives for wind developers to better adapt themselves to the market and thus increases the overall efficiency.

**Target Compliance**

Denmark's FIT system helped the country to fulfill the target in the early years. In 1990 Denmark set up a target of 1,300 MW by the end of 2000, which was quite ambitious at that time. The target was easily passed and in 2000 Denmark had already about 2400 MW of capacity. An updated target set up in 1996, aiming at building 1500MW by 2005, was also satisfied many years before the deadline. Denmark's experience shows the FIT's advantage in promoting capacity installations and meeting targets.

Currently Denmark has 20% of the electricity consumption supplied by wind. An ultimate target of the Danish policymaker is to supply 50% of the national electricity consumption by wind in 2025. This is the most ambitious plan on renewable promotion in the world.

**Price**

Using a fixed subsidy system, Denmark has a wind promotion cost almost decided by the compensation level. The level of the feed-in premium from 2009 is €34/MWh, adding to the average wholesale price at €46/MWh. Thus, the total remuneration level for the first 22000 hours (about ten years) is about €80/MWh. The compensation level is comparable to the German level. If we firstly assume no productivity difference among years and do not consider the capital cost (thus we use a payback method), the average payment over 20 years for each MWh of electricity in Germany is about €60/MWh (as calculated before), while in Denmark it is about €63/MWh.[3]

We can also introduce some possible discount rates and make a sensitivity analysis using a NPV method. The assumed discount rates are 5%, 6%, 7% and 8% respectively. The cash flows in the first ten years are assumed to be €80/MWh (electricity price + premium) and in the last ten years are €46/MWh (only the electricity price). The result of the sensitivity analysis is shown as follows, and we also make a comparison with the result obtained in the Germany section. It can be seen that with the discount rates the compensation levels in the two countries are very similar. The level in Denmark is slightly higher using our assumed discount rates.

[3] It is calculated through taking an arithmetic average of the compensation for 20 years, with the first ten years at €80/MWh (electricity price + premium) and the last ten years at €46/MWh (only the electricity price).

Table 7: The Average NPV of the Compensation Levels in Germany and Denmark

| Discount Rate | 5% | 6% | 7% | 8% |
|---|---|---|---|---|
| **Average NPV of the FIT per MWh over 20 years in Germany** | €40.3/MWh | €37.6/MWh | €35.2/MWh | €33/MWh |
| **Average NPV of the Compensation per MWh over 20 years in Denmark** | €41.8/MWh | €38.9/MWh | €36.3/MWh | €34/MWh |

The standstill of capacity growth during the period between 2003 and 2008 proved the importance of deciding the right price for the developers. In a feed-in system the price of the renewables is set up by the regulators. If an appropriate price is fixed, the uncertainty of the projects can be decreased. On the contrary, if the price is not suitable, there is no possibility to adjust it unless the regulators can change the policy. Nevertheless, a feed-in policy is usually designed for a long time frame in order to ensure the long-term security and reduce the regulatory risk faced by the generators. The flexibility of such policy is thus quite low. An inappropriate price will hamper the development of the industry for a long period, just as shown in the history of wind diffusion in Denmark. The premium of 100 DKK/MWh in the system is too low so the resource potential of the country cannot be exploited.

**Risk**

The feed-in premium scheme shares some characteristics with both the normal FIT and the green certificate scheme in terms of risk exposure. It reduces the uncertainty of the wind developers by providing a fixed compensation to cover part of the generation cost; on the other hand, the developers will still face the price risk and quantity risk from the market so there are strong incentives for them to reduce cost and adapt their production to the market demand. It retains the advantage of a TGC system but avoids adding too much uncertainty to the wind developers. In this sense, it is very suitable for a technology which is relatively more mature.

**Diversity**

Denmark also differentiates the compensation levels paid to different energy sources. However, the country does not aim to pursue a highly diversified energy portfolio but instead has a strong strategic reliance on wind power. This tendency can be easily observed from the latest tariff level released in 2009. For instance, solar electricity is only given a FIT of about €80/MWh, which is far from making it economically viable. The system thus provides only a symbolic support for solar PV despite of the FIT given.

Biomass has also an important position in Denmark's electricity portfolio and accounts for about 9% of the total electricity production in the country. The support level in the 2004 system was a FIT of about €80/MWh and in the new system it was changed to a feed-in premium of €20.5/MWh. The support level was actually reduced by more than €10/MWh considering an average electricity price of about €46/MWh.

Denmark still holds the second highest offshore wind capacity in the world, only second to the UK. In the 2009 regulation there is not a differentiated tariff design for the onshore and offshore wind power on the state level. Special premium is given directly to specific offshore projects and wind farms, based on the resource situation in the farms and the cost incurred. Considering the possibility that Denmark will put more strategic reliance on the offshore field, a separated feed-in premium may be given for offshore wind generation in the near future.

Table 8: Tariff Level for Different Renewable Sources in Denmark 2009(€/MWh)

| | Onshore Wind | Offshore Wind | Biomass | Small Hydro | Solar |
|---|---|---|---|---|---|
| **Tariff** | Market Price + 33.6 | Market Price + 33.6 | Market Price + 20.5 | 80.5 | 80.5 |

Source: EREF, 2009

## 4.5 Summary

The above sections have discussed the development of wind power and the influence of the support schemes in the four target countries: Germany, the UK, the US (Texas State as an example) and Denmark. A comparison of the main parameters is summarized in the following table and the difference between countries is explained in detail later in this section.

Table 9: Comparison of Wind Power Development in Four Countries

| | **Germany** | **The UK** | **Texas** | **Denmark** |
|---|---|---|---|---|
| **Scheme Types** | FIT | TGC | TGC | Feed-in Premium |
| **Resource Quality** | | | | |
| **Average Capacity Factor** | 17% | 25% | 23% | 25% |
| **Growth Indicators** | | | | |
| **Cumulative Installed Wind Capacity in 2009** | 25.8 GW | 4 GW | 9.4 GW | 3.5 GW |
| **Wind Generated Electricity in 2008** | 40.4 TWh | 5.8 TWh | 16.3 TWh | 7.6 TWh |
| **Target Compliance** | Yes | No | Yes | Yes |
| **Share in Electricity Consumption** | 7% | 1.7% | 6.9% | About 20% |
| **Compensation Level** | | | | |
| **Total Compensation per MWh** | ***€92*** for 5 years, ***€50.2*** for 15 years | 5 year ROC average***€57.3*** **+** Wholesale***€47*** | 5 year REC average***€4.5*** + PTC***€16.5*** for 10 years **+** Wholesale***€55*** | ***€33.6*** for 10 years + Wholesale ***€46*** |
| **Risk** | | | | |
| **Subject to Market Volatility** | No | Yes | Yes | Yes |

The four countries use different types of schemes to foster the development of renewable energy. Germany and Denmark use similar feed- in systems. The difference is that the FIT system in Germany secures the whole tariff paid to renewable generators while the feed-in premium system in Denmark guarantees only the premium part above the market price. The UK and Texas in the US both use tradable green certificate system. The two systems are rather similar except that the ROC market in the UK uses a special buy-out penalty mechanism which increases the complexity of the whole system.

The four countries all have above-average wind resources. The UK and Denmark both keep a high capacity factor of about 25% in recent years. Both countries also have excellent offshore potentials for future development. The average Texas capacity factor in recent years is slightly lower at about 23%. However, considering the high penetration rate in Texas and the fact that some sites cannot work at their full capacity due to transmission constraints and network pressure, the real capacity factor should be at least as high as the UK and Denmark ones. The resources in Germany are a bit less favorable. The country reported a capacity factor of 16.8% in 2009, which implies that the unit generation cost in Germany should be considerably higher than the other three places.

Despite having less outstanding resources, Germany can be considered as a successful example of using the FIT system to stimulate the penetration of renewable energy. The country has both a high capacity deployment rate and good target compliance records. 7% of its total power consumption comes from wind generation. The Texas state has also great achievements in its wind development. The installed capacity has surpassed the long-term targets set by regulators long before the specified deadline and contributes to 6.9% of the state’s total consumption. However, it is necessary to point out that the objective set by the Texas regulators is relatively conservative, and the state should have further potentials in exploiting its resources. Being the pioneer of wind energy, Denmark experienced some obstacles in the growth of wind capacity in the 2000s. The installed capacity ceased growth for about 6 years because of an inadequate feed-in premium level. The wind industry in the country regained its growth in 2009 when the support system was revised. The country now has 20% of the electricity demand met by wind power, which is the highest penetration rate in the world. The growth of the UK wind power market was not as satisfactory. The total installed capacity remains quite low and it fails to fulfill the targets designed by the policymakers, in spite of the good resources available.

The tradable certificate system is generally expected to create cost advantages over the feed-in system because it involves more market competition to create incentives for cost reduction. Whether this objective can be achieved depends on the functioning of the system. Below is a brief comparison of the total compensation paid to the wind generators for generating every MWh of electricity in the four markets:

- In Germany, the FIT for the first five years of a project is **€92/MWh**, and for the last fifteen years is **€50.2/MWh**.

- In the UK, the average ROC price in the recent 5 years is **€57.3/MWh**. The average wholesale electricity price is about **€47/MWh**.

- In Texas, the average REC price in the recent 5 years is **€4.5/MWh**. The PTC, as an additional support from the federal level, is €16.5/MWh for the first ten years of the project. The average wholesale electricity price is about **€55/MWh**.

- In Denmark, the feed-in premium given to the generators in the first 10 years of the project is **€33.6/MWh**. The average wholesale electricity price is **€46/MWh**.

We can compare the price levels in the four countries over a 20-year timeframe. The purpose here is giving a rough comparison in order to obtain a general picture of the compensation levels in the four countries, so we make some assumptions to simplify the comparison.

- The wholesale electricity price is assumed to stay at the current level over the 20-year period.

- The certificate prices in the UK and Texas are assumed to fluctuate within 20% of the 5-year average price we mention above.

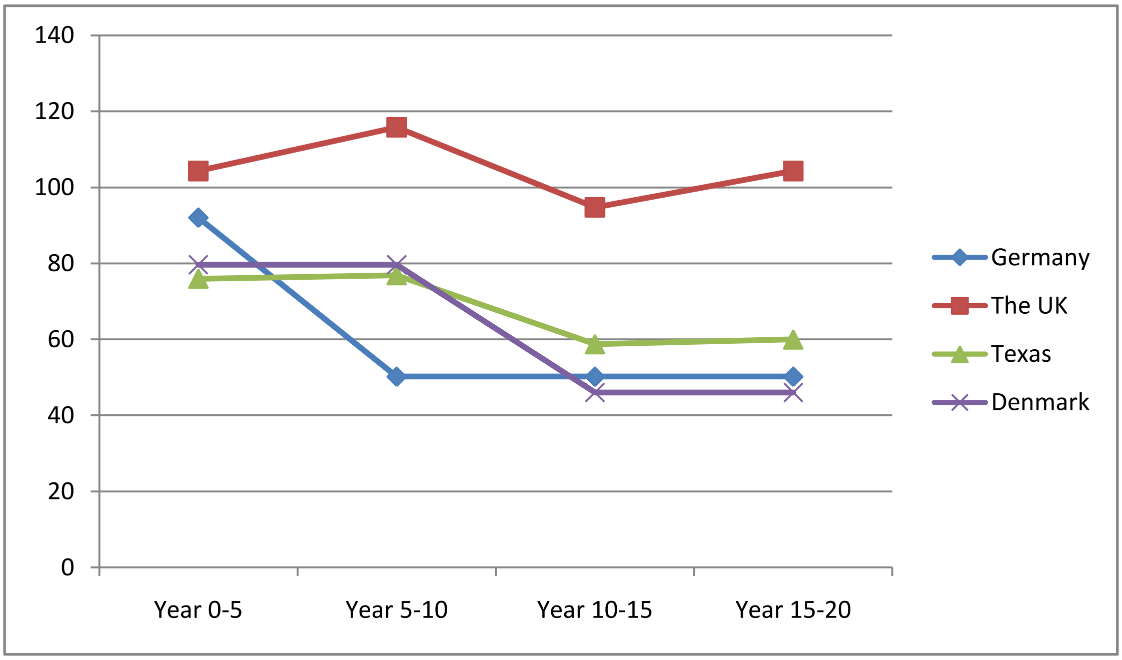


Figure 12: Compensation Levels to Wind Generators at the 2009 Standard (€/MWh)

From the comparison it can be seen that the UK has the highest extra compensation paid to the wind generators given our assumption. Texas, though having a low certificate price, has a quite high total compensation level due to the high electricity price in the region. The total compensation levels in Germany and Denmark are quite similar, as has been discussed in the Denmark section.

The high cost of the UK ROC system can be largely attributed to its buy-out penalty fee system. The buy-out fee creates incentives for existing renewable generators to undersupply because the demand surplus will raise the value of the ROCs. In addition, the ownership structure of the wind industry deteriorates the problem as a majority of wind capacity is directly or indirectly owned by the major generators. They also have incentives to control further investments because they are not willing to see the crash of ROC price. Furthermore, the price risk of the ROC market and the high upfront investment of the wind industry create entry barriers to small new investors. All these three factors together can explain why the UK market is undersupplied given the high ROC price.

The Texas market maintains high growth in the last decade; however, the regulators were conservative in measuring the resource potential of the state and set up relatively low renewable targets, so the capacity growth cannot be attributed to the certificate market. The targets were easily surpassed due to the excellent resources and the Production Tax Credit subsidy from the federal level which provides a fixed amount benefit to the generators. The certificate market was thus oversupplied and the regulators did not adjust the target accordingly. The certificate price became extremely low and can no longer function as a stimulus for new investments. Now only the Production Tax Credit from the federal level is supporting the Texas wind industry. The Texas system may have achieved the targets of the regulators, but most of the development of the market should be attributed to the PTC policy instead of the certificate scheme.

In the feed-in schemes the price of the renewables is decided by the regulators instead of the market. A mistake in deciding the price can have serious consequences. In 2001 the Danish policymakers set up a premium of about €13/MWh for the wind generators, which was considered too low by the market. The growth of the whole industry stopped for 6 years as new investments were not economically viable at the given price. The industry started to recover only when the price was changed in 2009. The case reflects the importance of setting a FIT that correctly reflects the cost borne by the renewable developers.

With regard to the risk issue, the wind developers in the UK and Texas are exposed to significantly more uncertainty than those in Germany and Denmark. Under a green certificate system the investors have to bear the volatility of both the certificate market and the electricity market. In addition, regulatory risk cannot be ignored as shown by the Texas case, where a conservative renewable obligation setting leads to the collapse of the market. The early success of the Texas market demonstrated that long-term contracts may be a solution to the risk exposure brought by a certificate market; however, a stable market environment should be established in order to maintain the enthusiasm of both the investors and the retailers to enter such long-term contracts.

The feed-in system provides high investment certainty and thus becomes efficient in promoting the market at an early stage. Nevertheless, guaranteeing a fixed income and priority network access, as conducted by Germany’s policy, may totally eliminate market competition and reduce the incentives for quality control and production adjustment. In comparison, the feed-in premium system in Denmark is a better combination of risk reduction and market competition: investors are secured a part of cash flow, but still have to adjust themselves actively according to the demand situation of the market. It fits well for a more mature market like Denmark.

# 5. Discussion of the Main Characteristics of TGC and FIT

From the country cases elaborated above, it is possible to observe some main differences of the tradable green certificate scheme (TGC) and the feed-in tariff measure (FIT). In the following chapter a comparison of the two frameworks is presented to evaluate their effectiveness and efficiency in promoting renewable energy.

## 5.1 Scheme Complexity

The designs of the FIT and the TGC schemes originate from two significantly different approaches. The feed-in scheme fixes the price while the TGC system decides the quantity and the market demand. Theoretically, a good design of both systems will require information of the resource potential of the country and the marginal cost curve of the industry. In practice this information is difficult to accurately estimate, so the design of both systems has to be conducted under imperfect information.

The design of a FIT relies mostly on the estimate of the cost structure of the industry. It is normally not very complicated to obtain the information on the current average generation cost. The difficulty of the mechanism lies on an accurate estimate of the average cost over a long period (including the capital cost), as a FIT policy is often guaranteed for a long time frame (usually more than 10 years) in order to provide a high degree of policy stability and reduce the regulatory risk. It is crucial to make reasonably accurate predictions of the learning curve of the industry to design a digressed tariff framework, which can provide more pressure on cost reductions for the generators. If the estimate of the learning curve is too positive, it may result in a lack of compensation to the generators. Consequently the generation cannot be economically viable and the effectiveness of the policy will be curbed. On the other hand, an over-negative estimate may lead to overcompensation to the generators and increase the total cost of promoting renewable energy.

Usually a too low compensation has more obvious effects and is easier to be detected. The history of the Danish wind industry is a good example of it. A timely revise of the system can solve the problem. A too high compensation is much more difficult to discover, given that the project cycle is often more than 20 years. Therefore, in most cases the FIT can only decide a price that is acceptable to the regulators, but cannot guarantee it is low enough. This is the primary concern on the FIT system.

The TGC system, on the contrary, relies on the design of an appropriate quota. If the quota is higher than what the market is willing to supply, the supply of green certificates from the market may be insufficient. As a consequence, the utilities or the retailers will then have to bear a higher financial pressure if a strict non-compliance penalty is implemented. Although it is reasonable to expect that a high price of the certificate will stimulate more supply, shorten the distance to the quota and ultimately drive down its price, a mature unbundled market structure is the prerequisite. Some defects of the market may stop the market from functioning well, as shown in the UK case.

A too low quota limits the development potential of a region. If the target set by the regulators does not reflect the resource potential of the region, the renewable resources cannot be well utilized. As shown in the Texas case, the quota designed for 2025 has been achieved in 2010 due to the compensation from the federal PTC. If there is no the involvement of the PTC, it is not possible for Texas to achieve such a wind power boom. The development of the great resource potential would be largely limited by the conservative goal-setting.

In summary, the main disadvantage of the FIT is the difficulty to guarantee that the price is close to the actual cost of the industry, while the TGC is weak when it comes to ensuring that the resources of the country is fully developed. The final choice of scheme will depend on the primary concern of the regulators: to ensure the lowest cost or to get more capacity developed.

## 5.2 Capacity Deployment and Target Compliance

The FIT system has proved to be more effective in stimulating new capacity building. Most of the capacity built currently in the world is promoted by a FIT scheme. The two most successful examples in Europe, Germany and Spain, are both using a FIT system to subsidize its wind penetration. The effectiveness of a FIT in promoting new capacity can be easily explained from its mechanism. As the tariff is usually constructed as the estimated cost plus a reasonable profit, investors can obtain a satisfactory profit by entering this business if they have an average performance. Provided that the tariff and the connection to the grid are guaranteed, there is low pressure from competition and low entry barriers. Theoretically new investors will flow in until all the promising sites are fully explored. The only thing the investors need to be concerned with is to lower its cost as much as possible to produce more profit, as the revenue is fixed. The long period of FIT enhances the investment certainty and further triggers new investments. Some specific policy designs in some countries, for instance the site-differentiated structure used in Germany, will also have positive influences on new penetration.

In the TGC system, the actual development will be largely determined by the quota set by the policy makers. It is pointed out that the mandated targets may set the upper limit for capacity development (Sawin, 2004). Such concern is reasonable because passing the mandated quota produces no new values for the generators, since the market may crash after that. An expected behavior for the existing players will hence be to keep the supply slightly lower than the quota level to maintain the price. Even if the resource potential is not fully explored, the production will not move forward. To conclude, the enthusiasm of the policymakers can to a large extent determine how far a TGC scheme can go. If only a conservative goal is set, an efficient TGC market will produce a relatively low price on certificates and the penetration level will remain low.

In terms of target compliance, theoretically the performance of the market under the

FIT is not related to the target set by regulators. However, since the FIT is very effective in stimulating new capacity installed, in most cases it can also meet the policy targets. The TGC is closely related to the target and theoretically it should be effective in target compliance. But a good compliance of the TGC target requires a strict penalty system and a low entry barrier, as discussed in the UK case.

## 5.3 Risk Reduction

The uncertainty level of a support system is also a significant factor that affects the level of new installations. As described in the previous chapters, the revenues of the generators under a TGC scheme are exposed to fluctuating prices both from the electricity and the certificate markets, which will inevitably increase their risk premium. This creates obstacles to the new investors compared to those under a FIT scheme, which provides a high degree of investment certainty over a long period.

The emergence of long-term contracts is often expected by researchers as a market-based solution to this problem (Van der Linden et al, 2005; Wiser et al, 2004). If long-term agreements can be reached between generators and retailers at a reasonable price to sell certificates, the risk involved in the system will be significantly reduced and new installations can be stimulated. The early successful years of the Texas market are often used as evidence to this argument (Langniss and Wiser, 2003). However, the emergence of long-term contracts must fulfill some requirements:

- **Compliance target:** The quota needs to be high enough to create a high demand for certificates.

- **Price uncertainty:** There should be an expectation of potentially high certificate price.

- **Compliance pressure:** The support scheme should at least have a binding target with high penalties for incompliance.

The above requirements need to be fulfilled in order for both the retailers and the generators to be willing to enter an agreement. If the quota is not high enough and the certificate price is too low, as shown in the Texas market, it is impossible for both parties to seek long-term contracts. On the other hand, the UK market is an example of a low compliance pressure. Though the retailers need to pay a buy-out fee for incompliance, the penalty will be recycled back to them in proportion to the certificates they have presented. Consequently, as long as they have delivered some certificates, they are able to get part of the penalty back, which reduces the binding power of the policy.

## 5.4 Cost reduction

A general concern on the FIT system is towards the cost-efficiency issue. The FIT is considered as an expensive policy as there is little competition between the generators. The industry is allowed to obtain a reasonable profit, which lessens the cost pressure of the producers. However, it is worthwhile to mention that the incentive for cost reduction is actually well embedded in the FIT mechanism. As the revenue level received is fixed, a lower operation cost will increase the profit of the generators. Therefore cost-minimization will be certainly placed as one of the core strategies for the generation companies. Besides, a large proportion of the wind generation cost is the upfront investment cost, which is highly dependent on the development of the wind technology. The competition of the equipment manufacturing industry can be fierce which will automatically drive the fixed cost down. Therefore, it is still reasonable to expect that the wind generation industry under a FIT scheme will follow a normal learning curve.

The TGC system is theoretically believed to be more cost-effective. More competition is involved in this system. New and more cost-effective generators can supply certificates at a lower price, taking away the market share of the old and high-cost companies. The competition is expected to create dynamics within the industry and to drive the industrial cost down. However, the price of the certificates still has to be higher than the extra generation cost of the renewable sources, in order to be effective in stimulating new investments. In this sense, it will not be significantly lower than the cost of a well-designed FIT. The higher uncertainty of the TGC scheme should also be taken into consideration. It may reduce the cost advantage of the system.

## 5.5 Quality Improvement and Network Integration

The quality of the generated electricity is also an important factor to be considered as it will significantly influence the result of the network integration. Renewable generated electricity is less stable than the conventional sources. In addition, many renewable sources, such as wind, are intermittent power, which is less reliable and provides higher pressure to the grid. The generation of electricity cannot be controlled and it may result in low level of generation during the peak demand or the opposite. A control on generation quality and adaption of the generation to the market demand hence become necessary.

The quality control issue is often regarded as a drawback of a FIT system. This is due to the priority access of renewable generation to the network, a policy frequently combined with the feed-in scheme in order to reduce the investment risk. As it is the system operators' obligation to accept all the electricity produced from renewable sources, the generators do not have pressure to improve the generation quality to facilitate integration, nor do they have sufficient incentives to adjust their production according to the market demand. As a consequence most of them implement a cost-minimizing strategy and produce as much electricity as possible.

Conversely, the quality pressure under a TGC scheme is much higher. The certificate market is separated from the electricity market, and the renewable generators are responsible for the marketing and sale of their electricity like a conventional generator. They may not be able to sell the electricity if the quality does not meet the required standard. They will try to reduce load fluctuation in order to avoid a possible balancing penalty from the regulators. They also have higher motivations to adjust the production to the market demand by running slightly below the full capacity to facilitate the grid conditions. A higher awareness on quality control and production adjustment can greatly facilitate the integration of renewable energy into the network and reduce the grid pressure.

The feed-in premium policy, adopted by Denmark, can be seen as an improvement of the FIT in this aspect. Under the feed-in premium scheme, the generators are only secured a fixed premium, but are wholly responsible for the sale of their electricity. Therefore they are subject to the same pressure described before as the ones under the TGC scheme and the generation quality will be improved.

## 5.6 Resource Utilization

If a country's objective is to fully explore its wind resources, the development cannot be limited only to those most windy areas. Besides, developing the less-windy sites can help to avoid the over-concentration of the wind farms in a specific region, which may challenge the network reliability of the region. In most cases, the FIT is more flexible than the TGC system in fully utilizing a country's resources.

The basic principle of a FIT system is to develop as many resources as possible at a stable and reasonable cost. The scheme is flexible and can be easily adjusted in order to support all the promising sites. Most of the FIT systems, for instance Germany and China, have site-differentiated tariff policies, which have been proved highly efficient. In Germany a wind field with less productivity than average in its first five years' operation can be entitled to a higher level of remuneration for a longer period, compared to those advantageous sites. In China the system is also straightforward. Four different tariff levels are applied in four regions, reflecting the resource quality and profitability of the wind mills. As the cost information is relatively easy to obtain, such a design does not increase the complexity of the system.

The differentiated tariff design helps to avoid waste of resources in some seemingly less promising sites, but it should be recognized that it will also increase the total average cost of promoting renewable energy. Therefore, the actual choice will have to depend on the renewable strategy of a country. The TGC system, conversely, aims to promote the renewable sources at a least possible social cost. This is a very different philosophy which will encourage the concentration of wind generation in the most cost-effective sites.

Under a TGC system it is also possible to promote less windy farms, but the actual implementation is more complicated and so far there are no successful examples in application. A possible solution is to grant more certificates for poor wind sites for every unit of generation, however, it is complicated to decide the appropriate number of certificates to be granted. Due to the fluctuating price in the certificate market, it may easily lead to overcompensation or insufficient compensation. For countries which would like to maximize the utilization of their wind resources, this will be a huge challenge when they try to adopt a TGC system.

## 5.7 Renewable Diversity

Similar to promoting wind sites with different resource quality, the promotion of a diversified energy mix will also highly depend on a country's energy strategy. Overall speaking, a feed-in system is more convenient and flexible to stimulate development of different resources, if the policy makers consider it necessary. Different energy sources can be granted different levels of the tariff to cover the necessary cost. This method is straightforward and an appropriate amount of compensation paid to the generators is easier to calculate. Another merit of the FIT is that different policies will not influence each other. As long as a company can control the generation cost under the tariff, the project can be profitable. There is no competition from other energy sources, which to some degree protects some immature renewable industries, such as the solar energy. Germany and Spain are both successful examples in using the FIT to support diversity.

The characteristics of the FIT have also made it more favorable to small scale generators, which are important sources of energy diversity. For some small distributed generators it may be difficult to compete with the big players in the electricity market and the certificate market. Priority grid access and a fixed payment can greatly reduce their risk and enable average household and small investors to enjoy the benefit from renewable investments.

In the early stage of many TGC systems diversity is usually not among the core objectives. The fundamental principle of the TGC mechanism focuses on the development of technologies with the lowest social cost. Theoretically production will mostly concentrate on the most mature technology. A TGC system can also promote renewable diversity but it requires more sophisticated designs. It can be conducted either by using an integrated certificate market or through issuing a new quota.

An integrated certificate market is implemented in the case of the UK. Renewable generators of various sources are given different amount of certificates for every kWh of electricity generated, reflecting different cost levels. This method may encounter difficulties as it is complicated to decide the right amount of certificates to be granted, the same problem as discussed in the resource utilization section. The price of certificates fluctuates and it is almost impossible to guarantee that the remuneration level to the generators is appropriate. In addition, under such a system competition exists across different sources, which may pose challenges to less mature technologies. It may happen that a large amount of certificates generated from wind sources will flow into the market, drive down the prices and take away the quota. Under such circumstances it is likely that ultimately most of the subsidy will still go to the lowest-cost technology.

Issuing a new quota scheme can avoid the influences from different sources and guarantee that the target technologies are promoted. Generators of the promoted source can get an independent price, which is determined by its own market and more correctly reflects the cost incurred. Texas is using a similar system by releasing a "non-wind" quota that is specifically for other technologies, but the system is not binding at present so the market has not really started to work. The shortcoming of issuing a new quota scheme is its complexity in administration and operation, both from the regulatory and the generator perspectives.

The table summarizes this chapter about the main characteristics of FIT and TGC.

Table 10: Comparison of Main Characteristics of FIT and TGC

| | **Feed-in System** | **Tradable Green Certificate Market** |
|---|---|---|
| **Stimulating New Capacity** | More effective | Less effective |
| **Target Compliance** | Effective | Effective |
| **Risk Reduction** | More effective | Less effective |
| **Cost Reduction** | Acceptable but not lowest | Lowest given good system functioning |
| **Quality and Network Integration** | FIT less effective; Premium system more effective | More Effective |
| **Resource Utilization** | More effective | Less effective |
| **Stimulating Diversity** | More effective | Less effective |

# 6. Evaluation of the Potential Norwegian-Swedish Common TGC Market

In this chapter a discussion is presented for the potential cooperation of Norway and Sweden in building a joint green certificate market. The chapter is structured as follows: First, there is a brief introduction to the agreement between Norway and Sweden regarding a green certificate market. Second, an overview is presented on the current green certificate market in Sweden, and an assessment is given on the outcome of the system. Third, the objective of Norway to entering such a market is tentatively described. After that the author evaluates the potential influence of a joint green certificate market on Norway and whether it could achieve its objectives. Finally, policy suggestions are made regarding this issue.

## 6.1 Introduction to the Agreement

On September 2009 Norway and Sweden agreed to establish a common green certificate market. The market is expected to start functioning from January 2012. This is the result of a five year negotiation since 2004. The actual quota and market design will be decided during 2010 and 2011. In 2009 Sweden announced that its 2020 target for renewable energy production is to increase by 25 TWh from the 2003 level. This is estimated to be about a 13 TWh increase from the 2012 level. Norway has agreed to adopt a renewable target with a similar level under the joint certificate market. A possible quota, as disclosed by Statnett (2010), would be a 26 TWh additional renewable electricity generation from 2012 to 2020 for the two countries in total, splitting into equal shares of 13 TWh. Support through green certificates will be offered until 2035.

There is only limited information disclosed regarding the design of the market. The most important information available to the public so far is that the certificate market will be technology neutral and size neutral. This has significant implication to the industry. As discussed in the UK and Texas case, a technology neutral system will not promote the diversity of renewable development. We have seen from previous evaluation that the system has a strong concern on cost minimization and the development will only focus on the eligible technology with the lowest cost.

## 6.2 Overview of the Swedish TGC System

Electricity consumption accounts for 36% of Sweden's final energy use. In 2008 Sweden produced 146 TWh of electricity. 97% of the country's electric production is emission free. Hydropower and nuclear power are the main sources, supplying respectively 47% and 42% of the country's electricity. Biomass-fueled plants supplied about 7% and wind power plants contributed to about 1%. The proportion of the electricity generated by fossil fuels has been substantially reduced since 2000s due to the rapid development of biomass-based generation. (Swedish Energy Agency, 2009).

The Swedish TGC system started operation in 2003. It organizes a similar certificate market as the UK and Texas do. Originally the quota obligation was imposed on the electricity consumers. In 2006 the mandated party was changed to the retailers. It is also a technology neutral system. Eligible renewable sources include wind power, biomass, geothermal power, solar power, small scale hydropower (<1.5 MW) and wave power. Combined heat and power plants (CHP), though not emission-free, are also included in the scheme. They all receive one certificate through generating one MWh of electricity.

Both the existing renewable capacity and the new capacity could be eligible to green certificates. In 2003 the existing plants could generate 6.5 TWh of electricity. The existing plants were guaranteed certificates until 2012 or 2014 (depending on whether they receive other government support). Newly-built plants can receive compensation from selling certificates for 15 years.

The initial quota was set to increase the share of renewable energy in total energy consumption from 7.4% in 2003 to 16.9% in 2010, which corresponded approximately to a 10 TWh increase in renewable generation from 2002 (I6.5 TWh in 2002 + 10TWh increase). In 2006 a new quota for 2016 was set to increase the generation from the 2002 basis by 17TWh. Subsequently in 2009 the target was adjusted to a 25 TWh increase from 2002 to 2020, so in total the targeted generation is 31.5 TWh (6.5TWh in 2002 + 25TWh increase). In each year the regulators will set up a specific quota. A strict penalty is imposed for incompliance and collected by the state. The fee is set to 150% of the average certificate price in the previous year. During 2003 and 2004, the penalty fee was limited to SEK 175 and SEK 240 respectively. In practice this worked as an efficient price ceiling, and thus considered to undermine the effectiveness of the system. Currently the regulators do not put any price cap for this penalty, so the effectiveness of the penalty system is high.

## 6.3 Evaluation of the Swedish TGC System

***Target Compliance***

The Swedish TGC system has good performance in meeting the quota. In 2008 8.5 TWh of new generation had been added to the 2002 level, keeping good compliance record. Since 2004 the compliance rate in each year has been higher than 99%, which can be largely attributed to a strict penalty system. The following table shows the quota compliance record between 2003 and 2008.

Table 11: Renewable Generation and Quota Compliance in Sweden 2003 - 2008

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|
| **Liable El Consumption (TWh)** | 63.3 | 97.4 | 97.6 | 97.1 | 96 | 94 |
| **Quota** | 7.4% | 8.1% | 10.4% | 12.6% | 15.1% | 16.3% |
| **Required Certificate (Million)** | 4.7 | 7.9 | 10.1 | 12.4 | 14.5 | 15.3 |
| **Fulfilled Certificate (Million)** | 3.5 | 7.8 | 10.1 | 12.4 | 14.5 | 15.3 |
| **Total Renewable Generation (TWh)** | 8,5 | 11 | 11,3 | 12,2 | 13,3 | 15 |
| **Compliance** | 77% | 99.2% | 99.9% | 99.9% | 99.8%[4] | 100% |

Source: Electricity Certificate System 2009, Swedish Energy Agency

Since 2003 the quota has been increased twice. When the renewable development was in a good trend a new and more ambitious quota was raised. The flexible adjustment of the quota guarantees the financial stability of the TGC market and helps to better exploit the country's renewable potentials.

***Generation Mix***

Of the 15 TWh of renewable electricity in 2008, nearly 70% was contributed by biomass and peat generation. This generation came mainly from biomass-based CHP plants. About 17% was from small scale hydropower. Although wind power has grown rapidly since 2006, its share remains quite small at about 13%.

A closer look at the installations of the renewable capacity reveals that most of the increased generation actually comes from improved productivity of the existing plants.

[4] Certificates generated in previous years can be banked and used for compliance. So although the generation in 2007 was lower than mandated, the compliance rate can still be almost 100%.

For instance, the biomass generation grew by about 50% from 2003 to 2008, but the capacity installation growth was only about 10%. The same applies to hydro and wind power. According to the Swedish Energy Agency (2009), only 2.5 TWh of the renewable electricity produced in 2008 were generated in the plants invested after 2003. The other 12.5 TWh was from those plants that were already in operation before the introduction of the TGC system. These plants increased their renewable output through improving the productivity in the biomass-based CHP plants or converting fossil-fueled plants to biomass-fueled. Such projects can be done with small capital input and low risk, so they are more welcomed by the investors.

Table 12: Renewable Development in Sweden by Sources 2003 – 2008

| | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** |
|---|---|---|---|---|---|---|
| **Biomass & Peat** | | | | | | |
| **Capacity (MW)** | 3,157 | 3,185 | 3,424 | 3,643 | 3,676 | 3,451 |
| **Generation (GWh)** | 6,327 | 7,671 | 7,926 | 8,594 | 9,049 | 9,599 |
| **Hydro** | | | | | | |
| **Capacity (MW)** | 491 | 504 | 517 | 540 | 558 | 598 |
| **Generation (GWh)** | 1,446 | 1,968 | 1,799 | 2,019 | 2,195 | 2,607 |
| **Wind** | | | | | | |
| **Capacity (MW)** | 401 | 472 | 530 | 583 | 831 | 1,074 |
| **Generation (GWh)** | 684 | 865 | 939 | 988 | 1,432 | 1,996 |
| **Total Generation** | 8,460 | 11,048 | 11,298 | 12,157 | 13,256 | 15,037 |

Source: Electricity Certificate System 2009, Swedish Energy Agency

Although wind power has not achieved a significant growth yet (The current market size is less than 1/3 of Denmark’s market), the current production has shown a good resource potential of the country. During 2003 to 2008 the wind power industry reached an average capacity factor of 20%. The resources are not as excellent as the sites in the UK and Texas, but still much better than some average quality sites like the ones in Germany. The primary reason for the low development of the wind power in the country is the technology neutral system. As the biomass-based CHP has considerably lower cost, most of the investments will go to those projects so the quota would be met with the lowest possible social cost. Besides, as illustrated in the previous chapters, under the TGC system investors will favor more the low fixed cost technology like biomass because it has lower capital input. Under the tech-neutral system, wind power can get substantial development only when the quota is set sufficiently high and when the resources of the lower-cost technology have been utilized. In this case the certificate price can be high enough to compensate for the investment cost of wind power. However, this may lead to over-compensation in the system, which is discussed in the next section.

***Cost Control***

The Swedish TGC system has managed to maintain a low certificate price. The price moved between 190 SEK/MWh and 250 SEK/MWh during 2003 to 2008. The following table lists the average prices of the six years. The average price level is about €23 / MWh, comparable to the compensation level for the wind power market in Texas (including the PTC part). Considering the increased generation and the cost level, the Swedish TGC system should be considered as cost efficient in social terms, as the target is met with very low social cost.

Table 13: Price Development of the Swedish TGC 2003 – 2008

| | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** |
|---|---|---|---|---|---|---|
| **Average Price (SEK)** | 201 | 231 | 216 | 191 | 195 | 247 |

Source: Electricity Certificate System 2009, Swedish Energy Agency

### *Allocation Effects and Profitability Issues*

Ensuring fairness is also a crucial task of a well-functioning TGC system. The costs and benefits should be reasonably allocated among the market participants. The idea of a TGC incentive is that the income received by the renewable generators from selling the certificates should cover their additional costs of developing the renewable electricity projects compared with the conventional electricity production. If the payments exceed the additional cost to a large degree, the overcompensation to the generators would be considered as a "windfall profit". This is because the additional payments do not lead to any extra contributions from the generators. The payments do not create new incentives.

As mentioned before, there was 6.5 TWh of the existing generation included into the TGC system in 2003. Most of these projects were actually already profitable or almost profitable (Bergek and Jacobsson, 2009). This arrangement in fact allowed them to obtain an abnormal profit. They could have been financially viable with zero or much lower subsidy.

Furthermore, 12.5 TWh out of the 15 TWh of renewable generation in 2008 was generated from plants that already existed before 2003 (Bergek and Jacobsson, 2009). The expansion of renewable output in these plants requires lower cost than the compensation of the certificate price. The Bergek and Jacobsson (2009) article estimates an average cost of expanding these plants at about 40 SEK/MWh based on data from 2001. In practice the cost might be substantially higher than this level, but these projects are still very likely earning abnormal profit from the TGC market considering an average certificate price of more than 200 SEK/MWh.

That is to say, although the Swedish TGC system has achieved both high renewable growth and low cost, there exists an allocation problem in the system. The social benefit gained could have been achieved through a lower consumer cost. A substantial part of the compensation becomes a source of windfall profit.

A key problem of a technology neutral TGC market is that theoretically the certificate price will be decided by the marginal cost of the most costly project built to satisfy the quota. In case there is a large difference in cost among the various resources promoted, the projects with lower cost will receive windfall profit. A technology-differentiated system, on the other hand, is less likely to create such problems.

This problem is closely related to Sweden's ambition in developing its wind resources in the future. The Swedish Parliament has set a national planning framework target for the wind power to deliver 30 TWh by 2020, of which 10 TWh would be offshore. Under the current system the prerequisite of a significant wind development is a sufficiently high quota and the full exploitation of the cheaper resources. At present the quota is not sufficiently high to stimulate wind development, so the certificate price is low. However, in the future if the two above-mentioned conditions can be reached, the large-scale development of wind power will raise the current certificate price substantially and lead to further overcompensation to the biomass, hydro and CHP projects. Due to the existence of the windfall profit, the Swedish system does not perform well in terms of the fairness in allocation.

***Summary***

The Swedish TGC system has established a challenging quota target and obtained good compliance record. The cost of compliance has been retained at a reasonable level. The system is therefore successful in achieving a political target with a low social cost. A good practice in the TGC system is the design of a strict penalty system, which guarantees a high compliance level. Besides, the timely enlargement of the quota level helps to retain the stability of the TGC market and increase the utilization of resources.

However, the technology neutral design creates an allocation problem among the market participants. The system is in fact subsidizing a large amount of projects which are economically viable. In the future if more onshore and offshore wind power plants are included in the system, the overcompensation problem will become more serious. The current benefit brought by the quota scheme could have been achieved at a lower average price for the consumers.

## 6.4 Overview of the Norwegian Energy System

Norway has the second highest electricity consumption per capita in the world. More than 50% of the country's energy consumption is in the form of electricity. Hydropower is dominant in Norway's electricity generation structure. 140 TWh of hydropower was produced in 2008, contributing to 98.5% of Norway's electricity production. According to the estimate of the Norwegian Water Resources and Energy Directorate (NVE, 2009), the total hydropower potential at the end of 2008 was about 205TWh (Including resources that are already developed and to be exploited). The current development has utilized about two thirds of the resources.

Due to hydropower's dominance and its advantage as a clean energy source, the development of other electricity sources in Norway remains quite low. Wind power, for instance, has only very limited deployment in Norway. By the end of 2008 Norway has installed only 431 MW of wind capacity (Enova, 2010), about 10% of the size of the Danish market. The total wind generation in 2009 was 980 GWh, consisting of less than 1% of the country's electricity production.

## 6.5 Analysis of Norway's Objectives

To analyze whether a common certificate market will be suitable for Norway, it is crucial to look at Norway's objectives in entering such a system. One of the main purposes of Norway is to promote its wind power. In spite of the low deployment, Norway's great wind resource potential cannot be ignored. With its long and windy coastline Norway has one of the most abundant resources in the world. The average wind speed in potential sites can be 7-9 m/s. In 2009 the average capacity of the wind sites in Norway was 26%, reflecting a similar resource quality to that in Denmark and the UK. In some good sites the full load hour can achieve 3800 hours, representing a very high capacity factor of 43.3% (Enova, 2010).

At present Norway does not have an operating support system for the wind power, and the investment support given by the government is rather limited (Enova, 2010). The introduction of the TGC market is expected to break the standstill.

Small scale hydropower is another renewable source that can be further developed. Among the hydro resources that have not yet been developed, there is a potential of about 17.9 TWh in small scale sites (NVE, 2009). Developing these sites will involve a relatively higher capital cost compared to the existing hydropower projects and require a subsidy program. Besides, the renewal of old hydro plants and the improvement of their productivity should also be within the policymakers' objectives.

Another main concern of the Norwegian regulators is the cost brought by the support scheme. Previously there were also proposals for a TGC market, but they were all rejected due to a potential high cost to the consumers. The cost concern is also the primary reason why the TGC system and the technology neutral design are chosen when entering the agreement with Sweden.

The political factor is also crucial for Norway to adopt a support scheme. In 2009 the EU RES Directive decided an objective of reaching 20% share of renewable energy in EU's total energy consumption by 2020. As the directive is EEA-relevant (EEA = European Economic Area. Norway is a member country.), it also applies to Norway. In order to reach the target set for Norway, the regulators would be willing to choose a scheme that can help to reach a target with high degree of certainty and low cost.

To summarize, the main expectations of the Norwegian regulators to adopt a support scheme would be as follows:

- Stimulating the wind power industry
- Promoting small scale hydropower and the renewal of old plants

- Reaching a political target with high certainty
- Reaching the target with low social cost

### 6.6 Evaluation of the Potential Common Market

In this section the suitability of a common TGC market for Norway and Sweden is analyzed. The discussion is organized in a list of critical issues that may affect the realization of Norway's main objectives.

***The Technology Neutral Design***

The technology neutral design is the most problematic issue in the potential TGC program. The original purpose of this design is to achieve the target by the lowest cost technology. However, the same as shown in the Swedish case, such a system will not discriminate between different sources with different cost and may create an allocation problem, compensating a lot the cheapest technologies.

Under a Sweden-Norway common market, the lowest cost technology is the hydropower in Norway. Most of the existing Norwegian hydropower projects are already profitable. Even if the system only applies to small scale hydropower (< 1.5 MW), many projects are still profitable. Although Norway has developed two thirds of its hydro resources, there is still a potential of about 60-80 TWh that can be exploited. It is highly possible to develop some profitable projects among these remaining resources. Part of the subsidies given to these projects will create abnormal profits.

The Swedish biomass generation and biomass-based CHP, in general, may have the second lowest cost. Some biomass generators are also close to being financially competitive. For those biomass-fueled plants that really require subsidies, the new system may seriously affect their operation in case that the total quota is not sufficiently high. Previously they could get compensation from the Swedish TGC system; under the new system, with the Norwegian hydropower plants possibly bringing down the certificate price, they may encounter losses in operation.

The wind power plants have the highest cost among these three most promising sources. Theoretically the investors will concentrate on the lowest cost technology until they are exhausted. The Norwegian wind power industry can benefit from the scheme only when the quota is set sufficiently high. However, even if the target can stimulate some wind growth, it will lead to the same problem that has been discussed in the Swedish system. The certificate price will be raised to a level high enough to support the wind power growth, but the other cheaper sources are thus over-compensated. This problem is almost inevitable under a technology neutral TGC system.

There could however be one exception. As the electricity price varies geographically, wind power may become competitive in the system in those regions where the electricity prices are very high. With a high electricity price the wind projects do not necessarily need a high certificate price. This has been observed in the Texas case where the wholesale electricity price is high (due to the high natural gas price) and therefore the subsidy level can be lower.

In conclusion, a technology neutral system is not suitable for Norway if developing a large amount of wind resources is indeed one of the main objectives of the policymakers. It is ineffective in stimulating Norway's wind resources and will cause over-compensation problems. In practice as the resources used for compliance (hydropower and biomass) have low cost, the certificate price may be low. But windfall profit may still exist in firms using these resources.

***Differentiating Resources***

Even if the TGC scheme is not technology neutral, it still has difficulty in properly differentiating resources, as discussed in the previous chapter. Granting more certificates to expensive technologies (the UK case) is not very efficient as it is difficult to decide the exact amount to be granted. Still it will commonly lead to over-compensation or lack of compensation. Setting individual quotas for different technologies (the Texas case) may be a better solution, but it will require establishing several certificate markets and thus increase the complexity, both for the regulators and the mandated parties.

***Target Compliance***

A TGC market should enable Norway to fulfill its environmental obligations with high degree of certainty. Given the cheap and abundant hydro and biomass resources in Norway and Sweden, as well as the good compliance record in Sweden, it can be expected that the future common market will also perform well in meeting the quota. A strict incompliance penalty will help to achieve this objective.

***Utilization of Wind Resources***

In addition to the technology neutral design, the TGC system itself is less effective in promoting wind resources than the feed-in system. Its higher uncertainty will lead to a greater capital cost to the wind projects. Projects with lower upfront investment and higher variable cost more likely benefit from it. The lower upfront cost leaves the investors more flexibility over the project life cycle. The variable cost can be compensated immediately when the certificates are generated so the cost better matches with the revenue stream. Even if the Norwegian wind projects can reach a similar cost as the Swedish biomass projects, investors may still prefer the latter because of the higher flexibility and lower risk level.

***Cross-country Subsidy***

Another controversial topic of a common TGC market between Norway and Sweden is the cross-country subsidy issue. Norway and Sweden both have obligations in the Kyoto Protocol and EU Emission Trading System (ETS). A key question is whether one country’s subsidy should support another country in meeting its climate change obligation? There should be a proper arrangement to make it fair for both parties.

A possible solution may be to set a common climate obligation for the two countries in the future international agreements. However, this will also be challenging as both countries still have their local support policies in addition to the TGC scheme. It will still be difficult to distinguish their respective financial contributions to the common obligation.

The interaction of local support policies and the TGC scheme will also be a potentially problematic area. The Texas case has shown how significantly the policies (PTC and RPS) interact with each other. The TGC system will support the technology with cost advantage. A cross-country TGC may give local authorities incentives to further subsidize the local plants, in order to make those plants cost-competitive and thus eligible for the certificates. For instance, the biomass plants in Norway have a higher average cost than those in Sweden. But assuming that there is a local investment support in Norway for biomass plants, they will require less compensation from the TGC market. Therefore they will win the competition against the Swedish plants and get the subsidy. This situation is unfair but can hardly be completely avoided.

***Political Pressure on Quota Setting***

Setting a proper quota is the most crucial issue in the successful design of a TGC system. It requires a careful evaluation of the country's resource potential and the cost structure of the promoted technologies. Political factors may become influential when a common quota is to be agreed by two countries. In most cases it will be the political pressure that makes the two countries compromise and set up compatible targets, instead of a scientific measurement of the countries' own situation. For instance, a recent presentation by Statnett (Austang, 2010) estimated the quota of the common TGC market. They estimated that in order for Sweden to meet its 2020 target of adding 25 TWh additional renewable generation from 2002 to 2020, it needs to increase 13 TWh from 2012 to 2020. Based on this Norway has to contribute also 13 TWh to the scheme, so in total the quota would be adding 26 TWh from 2012 to

2020.

Such an estimate is arbitrary. Norway and Sweden have very different resource types and potentials. It is not reasonable to simply require the two countries to have the same target. In addition, in a TGC system the common target is set for both countries and it is impossible to expect the two countries to get the same level of development. The common target should be set up according to both countries' resources situation.

***Summary***

The TGC market will help Norway in meeting some of its objectives. More hydropower resources can be utilized in Norway, and the old plants can get incentives to renew and increase the output. These projects will not require a substantial investment but can bring high environmental returns. Besides the TGC scheme can ensure Norway in fulfilling its environmental obligations under international agreements.

However, the technology neutral design should be revised in order to prevent the system from becoming a windfall profit generator. The current system will enable many hydropower and biomass plants to get abnormal profit, and thus make it unfair for the consumers.

The system also cannot satisfy the objective of developing the wind resources efficiently. In the short term all the certificates will probably be occupied by hydro and biomass projects; in the long run if wind power is used for compliance, the certificate price will be substantially raised and greatly overcompensate the lower cost projects. The difficulty is further compounded by the fact that a TGC system will involve high uncertainty for the wind developers.

A cross-country scheme and the interaction from local policies will further increase the complexity. It is difficult to ensure that the two countries get similar benefits from the system. Political factors may also affect the outcome of the system.

## 6.7 Policy Suggestions

In the last section some policy suggestions is made for the Norwegian regulators in promoting Norway's renewable resources. As the details of the TGC scheme have not come out, the suggestions can only concentrate on some general policy design aspects.

***Will a FIT better fit Norway?***

In many aspects, a FIT scheme may be more suitable to achieve Norway's objectives. Separate FITs can be set to promote the small scale hydropower, wind power and biomass resources. The advantage of the FIT in promoting high capital cost technologies has been elaborated in the previous chapters. It can effectively stimulate the deployment of Norway's wind resources. If the Norwegian regulators do not want to impose too much financial pressure on the consumers, the FIT for wind power can be set relatively lower, so only those sites with the best resource quality will be developed.

The tariff levels for different technologies can be strictly controlled according to their cost so there will not be a high level of overcompensation to the plants. In this sense, compared to a technology neutral TGC the FIT can ensure a better allocation of the benefits and costs among the market participants, which would better fit Norway's objective. But it is important to note that finding the correct level of a FIT is also difficult.

Another option for Norway is the feed-in premium system used in Denmark. It has the same advantages as a FIT, but is more market-based. Under the premium system the generators will adjust to the market demand, which better facilitates the integration of renewable electricity into the network. The Norwegian small-scaled hydropower market, for instance, has been quite mature and will be suitable for the premium system. The wind power market, on the other hand, is still immature and a FIT can help to reduce the investment risk.

***How to improve a TGC scheme?***

As Norway has entered an agreement with Sweden, the common TGC scheme is very likely to be implemented. There are some suggestions to improve the operations of the system.

**Differentiating Technologies:** The technology neutral system, as discussed before, will very likely create windfall profit for plants with low cost. The Swedish experience has proved this. A differentiated quota system can be considered as a better alternative. Like what have been done in Texas, separate quotas can be set for hydropower, wind and biomass. It has to be ensured that all the systems have mandated power and the targets are designed after careful measurement. Several parallel quota schemes may seem complicated for the retailers, but it is the best way to ensure that all the technologies get promoted with the least social cost involved. This system will be effective in achieving the four main objectives of the Norwegian regulators.

**Eligibility Standard:** One controversial issue in the Swedish TGC system is that it allowed 6.5 TWh of existing generation to be entitled to certificates when the system started operation. Most of these firms were already profitable and became overcompensated. In the new common system this problem can be alleviated through a well-designed access standard for the renewable generators. Setting an eligibility restriction on projects with different scales is important. The green certificates should not be granted to those projects that already very profitable without a TGC subsidy. For instance, the Texas system has a restriction on the size of the hydro projects, counting only those less than 25MW. This issue is particularly important in the Norwegian system in which hydropower is expected to take a dominant position. Setting such a limit is important but difficult. Generally small-scale hydropower projects tend to be more expensive than the larger ones, but it also depends on the conditions of different sites. The limit setting should carefully consider the average costs of the projects with different sizes. The main purpose here is to ensure most of the subsidy is collected by those projects that are really in need of support.

**Strict Penalty:** The high compliance rate in Sweden should be attributed to the strict penalty system. An ineffective punishment system will cause a low compliance rate and a high certificate price, as shown in the UK case. The Norwegian-Swedish common TGC market can consider using the same system as the Swedish one.

**Policy Interactions:** Interactions of the TGC market and the local policies adopted by the two countries should be carefully evaluated. Other support policies should be approved by the two regulators together, in order to avoid causing market distortion of the TGC market. Signals of destructive competition, such as local policies subsidizing local plants to make them more competitive in the TGC market, should be examined every year.

**Target Setting:** Overall speaking, the quota setting should be based on evaluation of the society's needs and the external effects, in order to decide what would be a reasonable cost of implementing the mechanism. The main purpose is to achieve the best solution for society (also in the long run) at minimum cost, including those cost that is difficult to reflect in an unregulated market.

If a technology-differentiated market is applied in the future common market, separated targets should be set for wind, hydropower and biomass. The targets should both reflect the resource potential and the regulators' ambition at developing that resource. If a technology neutral system is used, it should be noted that a big quota may lead to overcompensation to lower cost generators and high consumer costs. This is because if wind power is used to satisfy the quota, the certificate price will rise substantially and the hydropower and biomass plants will likely be over-compensated. A solution here may be to charge a special resource tax to the plants earning windfall profit, but the resulting system complexity may therefore become an issue.

**Target Updates:** The Swedish quota scheme has been updated twice since it started in 2003. The timely adjustment of the target ensured the stability of the market and provided confidence to the investors. A delay in target update may restrict the potential of the market from developing further.

# 7. Conclusion

For renewable energy to get further promoted and achieve its full potential of reducing the environmental impacts brought by energy consumption, it is essential to establish suitable support mechanisms which provide a stable environment for the development of the renewable projects, with a high increase in capacity construction and power generation, and a reduction in cost.

This thesis discusses this topic and studies the cases of the adoption of two major support frameworks – feed-in tariffs and green certificates, in four major wind power markets. From the case studies it could be concluded that the feed-in system, or the pricing approach, has been more effective than the TGC system, or the quota approach, in stimulating more installations and generation. The FIT can create a securer investment environment and therefore limit the risk borne by the project developers. Due to the straightforward setting of the FIT for the investors (giving subsidy for every unit of generation), it is thus more flexible to differentiate subsidy levels to renewable projects with different cost levels. In this sense it helps to utilize a country's renewable resources to the greatest extent and promote the diversity of renewable sources.

The TGC system has more concern on the cost perspective. Given a good system it is possible to achieve the lowest cost in remunerating the renewable projects. Also it is a more market-based approach, which requires the generators to act towards the demand of the market and thus facilitates the network integration. However, the extent to which the renewable sources would be promoted depends on the ambition of the policymakers. If only a conservative goal is set up, the development of the country's resources would be limited.

Considering these characteristics the choice of schemes depends largely on the policy objectives. If the goal of the policymaker is to maximize the renewable development within a reasonable cost level, the feed-in system is more suitable. If the objective is to reach a political goal to increase the green electricity generation to a certain level, and have more control on the total financial input used for the subsidy, the certificate market suits better.

The thesis also evaluates the prospect of the cooperation of Norway and Sweden to establish a common green certificate market. The analysis shows that although the Swedish TGC market has a good compliance record and relatively low cost, the system has performed poorly in the allocation of cost and benefits among different market actors. The problem lies in the technology neutral design and the decision to include already existing plants into the quota scheme, which results in over-subsidy on some firms which have lower generation cost.

A common TGC market can help Norway in exploiting its abundant renewable resources, especially the wind and small-scale hydropower sources. However, in order to avoid generating a large amount of windfall profit like what has happened in Sweden, it is suggested that the technology neutral design should not be adopted. The current system design agreed by the two governments will enable many hydropower and biomass plants to get abnormal profit. In addition the tech-neutral design may be less effective to support the wind power projects in Norway (depending on the cost of the different eligible technologies and the quota size), while this was claimed to be an important objective by the policymakers. Another aspect that can be improved is to establish a high eligibility standard. It is important to decide whether to include the existing firms into the system, and which types of the projects should be eligible. A careful market design is essential when adopting a green certificate scheme, in order to prevent possible market failure or market inefficiency.

# Reference


Adib, P. and Zarnikau, J. (2006) Texas: the most robust competitive market in North America. Electricity Market Reform – An International Perspective (2006) 383-415

Agnolucci, P. (2005) Wind electricity in Denmark: A survey of policies, their effectiveness and factors motivating their introduction. Renewable and Sustainable Energy Reviews 11 (2007) 951-963.

American Wind Energy Association (2009), Annual wind industry report. Available at: http://www.awea.org/reports/

Austang, A. (2010) Norsk-Svensk Sertifikatmarked "Hvordan vil dette bli bygget opp I Norge?" Available at:

http://www.energinorge.no/getfile.php/Austang%20Statnett.pdf

Baldic, R. and Niu, H. (2008). Recent history of electricity restructuring in Texas. Available at:

http://users.ece.utexas.edu/~baldick/classes/394V/Recent%20history%20of%20Texas.ppt

Baldic, R. and Niu, H. (2003). Lessons learned: the Texas experience. Available at:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.117.4946&rep=rep1&type=pdf

Blanco, M. (2009) The economics of wind energy. Renewable and Sustainable Energy Reviews 13(2009). 1372-1382

Bergek, A. and Jacobsson, S. (2010) Are tradable green certificates a cost-efficient policy driving technical change or a rent-generating machine? Lessons from Sweden 2003-2008. Energy Policy 38 (2010) 1255-1271

Bushnell, J., Peterman, C., Wolfram, C. (2007), California's greenhouse gas policies: local solutions to a global problem? Climate Policy, forthcoming, 2008

Cali, U., Ropenus, S and Schroder, S. (2009) Development of interaction between distributed generation and the distribution system operators. IMPROGRES, WP 2, Deliverable D2.

Center for Energy Economics. (2009), Lessons learned from Renewable Energy Credit (REC) trading in Texas. University of Texas at Austin.

Commission of the European Communities. (2005), The support of electricity from renewable energy sources. Available at:

http://ec.europa.eu/energy/res/biomass_action_plan/doc/2005_12_07_comm_biomass_electricity_en.pdf

Department of Energy and Climate Change (2009), Annual tables: Digest of UK energy statistics. Table 5.2&7.4. Available at:

http://www.decc.gov.uk/en/content/cms/statistics/source/electricity/electricity.aspx

Electricity Reliability Council of Texas. (2009), ERCOT's 2009 annual report on the Texas Renewable Energy Trading Credit Program. Available at:

https://www.texasrenewables.com/reports.asp

European Commission. (2010), EU Energy in figures 2010. Electricity Generated from Renewables. Available at:

http://ec.europa.eu/energy/publications/doc/statistics/ext_renewables_gross_electricity_generation.pdf

European Renewable Energies Federation. (2009), Prices for renewable energies in Europe: Report 2009. Available at:

www.**eref-europe**.org/dls/pdf/**2009**/09**eref**reportfinal.pdf

European Renewable Energies Federation. (2006), Prices for renewable energies in Europe: Report 2006. Available at:

www.**eref-europe**.org/dls/pdf/2007/**eref_price**_report_06_07.pdf

Frías, P., Gómez, T., Cossent, R. and J. Rivier (2009), Improvements in current European network regulation to facilitate the integration of distributed generation, Electrical Power and Energy Systems 31 (9), pp. 445–451.

Enova. (2010) Markedet for vindkraft i Norge.

http://www.fornybar.no/sitepageview.aspx?sitePageID=175

Fridolfsson, S. and Tangeras, T. (2008) Market power in the Nordic wholesale electricity market: a survey of the empirical evidence. IFN Working Paper No. 773, Research Institute of Industrial Economics

Frontier Economics. (2009) International transmission pricing review – A report prepared for the New Zealand electricity commission. Available at:

http://www.electricitycommission.govt.nz/pdfs/opdev/transmis/tpr/International-transmission-pricing-review.pdf

Global Wind Energy Council. (2007), Global Wind 2007 Report. Available at:

http://www.gwec.net/index.php?id=90

Global Wind Energy Council. (2009), Global Wind 2009 Report. Available at:

http://www.gwec.net/index.php?id=167

Hartnell, G. (2003), Renewable Obligation Certificates in the UK. Caddet InfoPoint, Issue 2/03. Available at:

http://www.r-e-a.net/document-library/policy-old/rea-news/GH%20ROC%20article%20InfoPoint%202_03%20electronic.pdf

Langniss, O. and Wiser, R. (2003), The renewable portfolio standards in Texas: an early assessment. Energy Policy 31 (2003) 527 – 535

Lipp, J. (2007) Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy Policy 35 (2007) 5481-5495.

Leuthold, F et al, (2008) Nodal pricing in the German electricity sector – a welfare economics analysis, with particular reference to implementing offshore wind capacities. Working Paper. Available at:

http://www.hks.harvard.edu/hepg/Papers/Nodal_Pricing_0905.pdf

Mitchell, C., Bauknecht, D., Connor, P.M. (2004) Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany. Energy Policy 34 (2006), 297-305

Munksgarard, J. and Morthorst, P. (2008) Wind power in the liberalized power market – policy measures, price impact and investor incentives. Energy Policy 36 (2008) 3940-3947

Musgens, F. (2006) Quantifying market power in the German wholesale electricity market using a dynamic multi-regional dispatch model. The Journal of Industrial Economics, 2006

Non-Fossil Purchase Agency. (2010), Auction price of ROC. Available at:

http://www.e-roc.co.uk/trackrecord.htm

NVE. (2009) Energy in Norway 2008. Available at:

http://www.nve.no/en/Energy/Energy-in-Norway---a-brief-annual-presentation/

Ofgem. (2009). Addressing market power concerns in the electricity wholesale sector – initial policy proposals. Available at:

http://www.ofgem.gov.uk/Markets/WhlMkts/CompandEff/Documents1/Market%20Power%20Concerns-%20Initial%20Policy%20Proposals.pdf

Oko-Institut. (2004). Regulatory roadmap for Germany, Discussion paper. Available at: http://www.ecn.nl/fileadmin/ecn/units/bs/SUSTELNET/wp5_germany.pdf

Ragwitz, M., & Huber, C. (2005). Feed-in systems in Germany and Spain and a comparison. Karlsruhe, Germany: Fraunhofer Institut fur Systemtechnik und Innovationsforschung.

Renewable Energy Association. (2009), Wind power in the UK. Available at:

http://www.r-e-a.net/power/wind-power/UK_overview

Rickerson, W and Grace, R. (2007), The debate over fixed price incentives for renewable electricity in Europe and the United States: fallout and future directions. Heinrich Boll Foundation.

RWE Group. (2009). Electricity price in Germany. Available at:

http://rwecom-online-report-2009.production.investis.com/en/lagebericht/wirtschaftliche-rahmenbedingungen/strompreise.aspx

Schwarz, H., Lang, C. and Meier, S. (2007) Market power in the German wholesale electricity market: what are the political options? Institute of Economics, University of Erlangen-Nuremberg

Statnett. (2010)  El Certificates. Available at:

http://www.statnett.no/en/The-power-system/Energisertifikater/Elsertifikater/

SUEZ. (2005) ERCOT nodal market design: Q&A. Available at:

http://www.gdfsuezenergyresources.com/Ourexp/documents/Nodal092605.pdf

Swedish Energy Agency. (2010) Energy in Sweden 2009. Available at:

http://www.energimyndigheten.se/en/Facts-and-figures1/Publications/

Swedish Energy Agency. (2010) Elcertifikatsystemet 2009. Available at:

http://www.energimyndigheten.se/en/International/Instruments/The-electricity-certificate-system/

Texas State (1999), Texas Senate Bill No. 7 Texas Electric Restructuring Act. Available at: http://getpurenergy.com/states/forms/SB7.pdf

Texas State (2005), Texas Senate Bill No. 20

Available at: http://www.legis.state.tx.us/tlodocs/791/billtext/html/SB00020F.HTM

Toke, D. (2005), Are green electricity certificates the way forward for renewable energy? An evaluation of the United Kingdom's Renewables Obligation in the context of international comparisons. Environment and Planning C: Government and Policy, 23(3), 361-374.

TradeWind. (2009) Integrating Wind: Developing Europe's power market for the large-scale integration of wind power. Available at:

http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/TradeWind_Report_01.pdf

Union of Concerned Scientists (2009) Production Tax Credit for Renewable Energy. Available at: http://www.ucsusa.org/clean_energy/solutions/big_picture_solutions/production-tax-credit-for.html

Van der Linden, N. H. et al, (2005). Review of international experience with renewable energy obligation support mechanisms. Report No.ECN-C-05-025.

Energieonderzoek Centrum Nederland.

Weight, H. and Hirschhausen, C. (2008) Price formation and market power in the German wholesale electricity market in 2006. Energy Policy 36 (2008) 4227-4234

Wiser, R., Namovicz, C., Gielecki and M., Smith, R. (2008), Renewables portfolio standards: a factual introduction to experience from the United States. Lawrence Berkeley National Laboratory

Wiser, R., Porter, K. and Grace, R. (2005), Evaluating experience with renewable portfolio standards in the United States. Mitigation and Adaptation Strategies for Global Change. (2005) 10: 237-263.

Wiser, R. and Bolinger, M. (2008) 2008 Wind technologies market report. US Department of Energy. Energy Efficiency and Renewable Energy.

Wiser, R. and Bolinger, M. (2009) 2009 Wind technologies market report. US Department of Energy. Energy Efficiency and Renewable Energy.